IRON AND STEEL BOARD

RESEARCH IN THE IRON AND STEEL INDUSTRY

SPECIAL REPORT 1963

LONDON

HER MAJESTY'S STATIONERY OFFICE

1963

Iron and Steel Board,
Norfolk House,
St. James's Square,
London, S.W.1.

OFFICE OF THE CHAIRMAN.

20th November, 1963

SIR,

In the exercise of their duties under section 3(1) of the Iron and Steel Act, 1953, the Iron and Steel Board have prepared the attached report on the arrangements for the promotion of research relating to the iron and steel industry.

I have the honour to be, Sir,

Your obedient Servant,

R. C. Musgrave

Chairman.

THE RIGHT HON. FREDERICK J. ERROLL, M.P.,
MINISTER OF POWER.

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Appendices

Preface

THIS report surveys the arrangements for the promotion of research in the iron and steel industry. The Iron and Steel Board wish to thank the members of their Technical Advisory Panel for the valuable advice the Board have received from the Panel in connection with this survey. The Board also gratefully acknowledge the large amount of help that has readily been given by representative organisations in the industry, by the industry's research associations and by many companies and individuals.

Chapter 1

Introduction

The Duties of the Board in Relation to Research

1. Under the Iron and Steel Act, 1953, the Board are responsible for exercising a general supervision over the iron and steel industry with a view to promoting the efficient, economic and adequate supply under competitive conditions of iron and steel products. The Act further provides that the Board shall in particular keep under review (among other things) the arrangements for the promotion of research relating to the industry. If these arrangements appear to the Board to be inadequate, it is the duty of the Board, having consulted such representative organisations as they consider appropriate, to take such steps as the Board think practicable and desirable. For this purpose the Board may make grants or loans in aid of research relating to the iron and steel industry, and have conditional powers to require contributions from producers of iron and steel sufficient to defray such expenditure. The Board may not, however, undertake research themselves.

2. Most of the products with which the Board are concerned are made by the part of the industry that is represented by the British Iron and Steel Federation;* it will be referred to in this report as the general branch of the industry. The other two, traditionally separate, branches of the industry, namely ironfounding and steelfounding, comprise the manufacturers of iron castings and of steel castings respectively. (The casting of steel into ingots or semi-finished products are activities of the general, and not of the steelfounding, branch of the industry.) The ironfounders are represented by the Council of Ironfoundry Associations; this Council and the Council of Iron Producers are associated in the Joint Iron Council which thus represents both the users and the producers of foundry iron. The steelfounders are represented by the British Steel Founders' Association.

3. The Board's responsibilities in relation to research clearly require, in the first place, that the Board shall keep themselves informed of the progress of research on iron and steel, both in this country and also abroad in so far as research in other countries may be relevant to British needs. The Deputy Chairman of the Board is a member of the Councils of the British Iron and Steel Research Association and of the British Cast Iron Research Association. The Board's technical staff keep in touch with the industry's research activities, and attend technical conferences both in this country and overseas.

4. The Board also took steps, not long after they were set up, to obtain quantitative information about the resources applied to research in the industry.

* The producers of home ore are represented by the National Council of Associated Iron Ore Producers.

A questionnaire, which at the Board's request the British Iron and Steel Federation issued to its members in 1955, provided information as to research expenditure, and the staffs employed on research, in the general branch of the industry at that time.

Origin and Scope of the Present Report

5. It was apparent to the Board that in general the technical performance of the industry was good and that in a number of directions, for example the use of lean ores in large blast-furnaces and the production of high-quality steel from iron made from lean ores, British processes were unsurpassed in any other country. On the other hand, it was observed that, while the industry's programme of expansion and modernisation provided for the introduction of new processes such as continuous casting, vacuum casting and the use of oxygen converters for steelmaking, the companies installing such processes frequently had to rely on foreign patents and " know-how ". It was also observed that, in comparison with several other British industries, the expenditure of the iron and steel industry on research was small in relation to the size of the industry. These observations raised the question whether the industry's arrangements for research were adequate and, early in 1959, the Board decided to make a comprehensive review.

6. After considering a preliminary report from their staff, the Board decided to set up a Technical Advisory Panel to assist them with their review of research and with other technical matters; the Board felt that it would be beneficial to have the advice of a small group of persons with special knowledge and experience in the field of research and its practical application both in the iron and steel and in other industries. The British Iron and Steel Federation agreed to co-operate in setting up the Panel and to assist in its work. The composition of the Panel is given in Appendix I; a representative of the Federation attends meetings of the Panel as an observer.

7. The Board also took steps to obtain information as to research expenditure, and the staffs employed on research, in all branches of the industry in 1959. At the Board's request, the British Iron and Steel Federation and the British Steel Founders' Association obtained information from their respective members. The Board, after consulting the Joint Iron Council and the British Cast Iron Research Association, obtained information from a number of the larger ironfounders. The more important items of information obtained from the general branch of the industry were brought up to date in 1962 by means of a further enquiry undertaken at the Board's request by the British Iron and Steel Federation.

8. The present arrangements for research in the iron and steel industry are described in chapters 2 to 4 of this report. Some information as to the arrangements for iron and steel research in other countries is provided in chapter 5. An account of progress and achievements in iron and steel research since the war is given in chapter 6. Most of the information in these chapters is not new, but the Board believe that it has not previously been brought together. Whether the industry's present arrangements for research are adequate is considered in chapter 7. The Board's main conclusions are summarised in chapter 8.

Questions of Definition and Measurement

9. A distinction is frequently made between research and development. Research may be defined as organised experimental investigations into the materials, processes and products of an industry and development as the work involved in carrying forward the results of research up to but not including the stage of commercial production. However, the boundary between research and development cannot be clearly defined. In this report " research " should be read as including " development " unless the contrary is implied.

10. The research effort of a manufacturer or an industry may be measured in a variety of ways, for example, in terms of annual expenditure, the total staff employed on research or the number of qualified scientists and engineers (Q.S.E.) employed on research. There is no generally accepted definition of research nor will any definition be uniformly interpreted by all the manufacturers of whom enquiries may be made. To determine expenditure on research, it is often necessary to apportion costs that are common to research and other activities. Figures obtained from manufacturers generally relate to accounting years not all ending on the same date. Thus measurements of the research effort of an industry are estimates and approximations of limited and varying accuracy. Measurements of the research efforts of different industries will not be fully comparable for the further reason that circumstances and accounting practices vary from one iudustry to another. For example, some industries proceed by way of prototype development to quantity production and, in such industries, the cost of designing and making one or more prototypes is often charged to development; in other industries, such as shipbuilding and some branches of engineering, " one-off " production is the rule and the cost of the development work going into the first ship, or the first machine of its kind, is usually charged to production.

11. In the enquiries made by or on behalf of the Board in 1955, 1959 and 1962 the definitions of research were essentially the same as those used by the Department of Scientific and Industrial Research and the Federation of British Industries in enquiries that are referred to in para. 12 below; all these definitions included development as well as research. One special feature of research in the iron and steel industry is that the industry carries out a considerable amount of experimental work on full-scale plant in the course of commercial production. The cost of such work is often not separately recorded and it appears not to have been included in the replies of some companies to the enquiries made by or on behalf of the Board in 1955, 1959 and 1962. In this respect the estimates of the research effort of the iron and steel industry are probably understated in comparison with the estimates that have been made for some other industries.

12. Since it would be unreasonable to expect as large a research effort from a small industry as from a large one, the size of the industry must be taken into account in any attempt to judge whether an industry's research is adequate. It is usual to consider what may be termed the research ratio of an industry, i.e. the ratio of the iudustry's research effort to the size of the industry. The size of an industry can be measured in many ways, for example, by its gross output (i.e. the value of its turnover), by its net output or added value (i.e. the gross output less the value of raw materials and fuel consumed), by the total number of its employees or by the value of its fixed assets. The various measures of

the research effort and the size of an industry lead to a variety of measures of its research ratio. Estimates of research ratios for a large number of industries or groups of industries have been made in the course of well known enquiries carried out by the Department of Scientific and Industrial Research (D.S.I.R.) and by the Federation of British Industries (F.B.I.) into research and development in British manufacturing industry. In the reports of these enquiries estimated research ratios were given in the following measurements:—

Enquiry	Measurement of research ratios
D.S.I.R., 1955 (*a*) ..	Annual expenditure on research for each employee in the industry.
	Research expenditure as a percentage of turnover.
	Research expenditure as a percentage of net output.
D.S.I.R., 1959 (*b*) ..	Research expenditure as a percentage of net output.
F.B.I., 1960 (*c*) ..	Number of Q.S.E. employed on research for each 100 employees in the industry.
	Number of Q.S.E. employed on research for each £100,000 of fixed assets.
	Annual expenditure on research for each 100 employees in the industry.

Notes:

(*a*) Estimates of Resources Devoted to Scientific and Engineering Research and Development in British Manufacturing Industry, 1955—Table 11 on page 24. (H.M. Stationery Office, 1958).

(*b*) Industrial Research and Development Expenditure, 1958—Table III on page 6. (H.M. Stationery Office, 1960).

(*c*) Industrial Research in Manufacturing Industry, 1959–60—Table 2 on page 66. (Federation of British Industries, December, 1961).

13. In the reports referred to, it was made clear that estimates of research ratios were not put forward as a means of judging whether or not any industry was carrying out an adequate amount of research. Great caution should be exercised in any attempt to judge the adequacy of the research effort of an industry by comparing its research ratio with those of other industries. Industries are diverse in their circumstances, structures and techniques, in their needs for scientific information and in their opportunities to apply it; there is no inherent reason why the needs of an industry for research should be proportionate to the size of the industry. In addition, estimates of research ratios are not fully comparable between one industry and another; and the result of a comparison may also depend on the method of measurement employed. The validity of quantitative tests of the adequacy of an industry's research is further considered in chapter 7 (paras. 1–5) below.

Chapter 2

Outline of the Arrangements for Research in the Iron and Steel Industry

1. This Chapter describes the main features of the present arrangements for research in the iron and steel industry in this country; it also includes a short account of their history (paras. 11–19). The arrangements for research in the general branch of the industry are described in greater detail in chapter 3 and those of the foundry branches in chapter 4.

2. Industrial research in the United Kingdom is organised in a variety of ways. Most large manufacturing concerns undertake research for themselves; the research may be carried out in a central establishment or in departments of manufacturing units or partly in both of these ways. In industries that consist mainly of a few large companies, e.g. the chemical industry, the bulk of the industry's research is likely to be carried out by companies individually.

3. In many industries, however, co-operative research associations play an important and sometimes predominant part. These associations are supported by the industries they serve and most of them receive grants from the Government through the Department of Scientific and Industrial Research (D.S.I.R.). In many of the industries that include a large number of small firms, this form of association is the main centre of the research activity of the industry; the foundry, laundry and textile industries are examples. In general, the results of the work of a research association are communicated to all its members. Some associations are, however, willing to carry out additional research on a confidential basis for members who pay for the work.

4. There are also a few private organisations that undertake research on a commercial basis for fee-paying clients, the results of the work being confidential to the client. Organisations of this kind are being increasingly used for industrial research in this country; but they have not developed on as large a scale as in the U.S.A., where co-operative industrial research associations of the kind familiar in this country are scarcely known.

5. Many industries support research in the scientific departments of universities and at colleges of technology, either by grants, scholarships or endowments, Much university research is of a " pure " or " fundamental " kind. Such work frequently does not have much immediate application in manufacturing industry, but it augments the fund of scientific knowledge on which manufacturing technologies are based. It is of immediate benefit to industry in that it provides a source of trained research workers. Research at universities and technical

colleges is not, however, confined to work of an academic character. Some institutions send their students to take part in works experiments. For example, students of the Royal Technical College, Glasgow, have taken part in experimental studies, carried out at local iron and steel works, of the performance of furnaces.

6. A great deal of industrial research is carried out in Government scientific establishments such as the Building Research Station, the Warren Spring Laboratory and the National Physical Laboratory of D.S.I.R. Some of these establishments undertake special work requested and paid for by industries or companies.

7. The iron and steel industry employs all the foregoing forms of organisation for research. The major companies have their own research departments which investigate not only problems of particular concern to the company, but also problems of general interest to the industry. The results of many of these studies are communicated to the industry, either through the industry's research associations or by publication.

8. The industry supports three research associations—the British Iron and Steel Research Association, which is the largest co-operative association for industrial research in the United Kingdom; the British Cast Iron Research Association; and the British Steel Castings Research Association. It makes grants to other research associations working in related fields, for example to the British Ceramic Research Association, which investigates problems of refractories, and to the British Coal Utilisation Research Association. There is also close contact between the British Iron and Steel Research Association and several other research associations, for example the Cutlery and Allied Trades Research Association, the File Research Council, and the Spring Manufacturers Research Association.

9. The industry also supports research projects in several universities and makes use of private research organisations and Government scientific establishments; but since the industry has extensive research facilities of its own, its call on outside laboratories is not great.

10. There should also be mentioned, although it is not discussed in this report, the considerable amount of research on iron and steel that is carried out by plant manufacturers, by suppliers of raw materials, and by users of steel. The larger manufacturers of ironworks and steelworks plant have recently greatly expanded their research facilities. The suppliers of industrial gases carry out a good deal of research on oxygen steelmaking, on flame cutting, and on the degassing of steel by the use of inert gases. Important users of steel, such as the Service Departments, carry out research on the metallurgy of steel and discuss the results with the industry.

The Development of the Present Arrangements for Research*

11. In the industry's early years, the major technical developments came from the work of inventors who experimented on what would now be regarded as a pilot-plant scale. This was the method used in the eighteen-fifties by Bessemer and Siemens in their well known inventions of new steelmaking

* Fuller information may be found in " A History of the British Steel Industry " by J. C. Carr and W. Taplin. Basil Blackwell, Oxford, 1962.

processes. Twenty years later, the work of Thomas and Gilchrist on the basic-converter process was carried out on a pilot plant belonging to the Blaenavon Iron & Steel Company. As the industry grew, the classical processes were improved, mainly by the introduction of larger plant units and mechanical handling devices, in order to secure larger outputs. Laboratory work was, for the most part, confined to academic circles; practical steelmakers conducted their operations by trial and error, developing working rules through experience and often in conditions of secrecy. In the latter part of the nineteenth century and thereafter until the 1914 war, little genuine research work was done by companies other than manufacturers of alloy steels.

12. In the middle of the nineteenth century the more far-sighted manufacturers of iron and steel began to recognise the benefits of collaboration in technical matters; and in 1869 The Iron and Steel Institute was set up for the discussion of practical and scientific questions connected with the production of iron and steel. The Institute started co-operative research through committees in a small way soon after its inauguration; but the value of the Institute as a source of technical expertise was first fully realised during the 1914 war when it became the channel of communication between the Government's newly formed Advisory Council on Scientific and Industrial Research and the iron and steel industry.

13. The National Federation of Iron and Steel Manufacturers (which preceded the British Iron and Steel Federation) was formed in the period between the wars. The National Federation quickly recognised that the industry was not as technically advanced as it should be, and that in particular there was an urgent need for greater economy in the use of fuel. Accordingly it set up a technical department to study fuel consumption and fuel economy in the industry. The interests of the two bodies engaged in co-operative research, namely the National Federation (whose technical department was concerned mainly with fuel and with the design of furnaces) and The Iron and Steel Institute (whose committees were concerned mainly with metallurgy), were subsequently brought together by the setting-up of the Iron and Steel Industrial Research Council. The committees of the Institute were then superseded by joint committees of the Institute and the National Federation.

14. The Iron and Steel Industrial Research Council was financed by the National Federation. It also received a grant from D.S.I.R. and came to be generally regarded as a research association. Although it had practically no laboratories of its own* and only a relatively small staff, it was responsible for valuable progress in the design and operation of blast-furnaces and of steel furnaces, and in metallurgical research. This progress was made through programmes of research supervised by committees most of whose members were drawn from the staffs of companies. These companies shared most of the research and carried it out in their own works and laboratories. Thus one works would undertake blast-furnace trials, another would organise a series of open-hearth experiments and another would section a large ingot, possibly sending samples to be analysed in the laboratories of yet other companies. Some of the

* By arrangement with the Imperial College of Science and Technology in London, some work on blast-furnaces was carried out under the direction of Professor Bone, and later of Dr. H. L. Saunders, in laboratories belonging to the College. The Corrosion Committee of the Council had a small laboratory in Birmingham, with exposure stations in various parts of the world.

work was also carried out at universities under contracts or in return for grants made by the Council. The Council's committees were served by a small central staff who provided specialised advice and disseminated the results of the work.

15. During this period, that is from about 1928 to 1939, most of the research undertaken by companies, apart from work done for the Research Council, was directed to improving the operation of existing plant, to improving existing products and to developing new alloy-steel products including clad steels.

16. After the 1939 war there was an upsurge of activity in research. The first major decision was that the industry could no longer be satisfied with a research association that depended so largely on the goodwill of companies for facilities for experimental work. The British Iron and Steel Research Association (B.I.S.R.A.) was inaugurated in 1944, to take over and expand the work previously organised by the Iron and Steel Industrial Research Council. B.I.S.R.A. had in 1945 an income of £70,000 from the British Iron and Steel Federation and a grant of £30,000 from D.S.I.R.; the total income of the Iron and Steel Industrial Research Council had amounted in 1939 to about £50,000 a year. The Association established laboratories in London and Swansea as soon as circumstances allowed and subsequently extended them in Sheffield and Middlesbrough.

17. The setting-up of B.I.S.R.A was not, however, regarded by most of the larger companies as a substitute for increasing their own research efforts. While B.I.S.R.A. was developing, several of the larger companies either extended their existing laboratories or built entirely new ones. Some companies preferred to carry out all their major research projects in large central laboratories serving all the operations of the company; others preferred an organisation in which research and production were more closely associated.

18. The development of the arrangements for research in ironfounding took a different course. Because the ironfounding industry includes a large number of small companies, it was one of the first to set up a co-operative research association, namely the British Cast Iron Research Association (B.C.I.R.A.) which was incorporated in 1921. Many ironfounders look to B.C.I.R.A. not only for their research requirements but also for help with their routine scientific work.

19. The steelfounding branch of the industry also consists mainly of units that are too small to undertake research for themselves on a substantial scale. The number of units in this branch of the industry is, however, much fewer than in the ironfounding branch; and some small steel foundries are served by the research departments of the large engineering companies to which the foundries belong. When B.I.S.R.A. was set up, it had a division that took over the projects of the Steel Castings Research Committee of The Iron and Steel Institute. In 1950 the steelfounding branch of the industry decided to make its own arrangements for co-operative research. The work was at first done, without the help of a D.S.I.R. grant, by the Research and Development Division of the British Steel Founders' Association. The British Steel Castings Research Association was incorporated in March, 1953, and started to receive D.S.I.R. grants in 1954.

Chapter 3

The Research Arrangements of the General Branch of the Iron and Steel Industry

1. The estimates, given in the following table, of the research expenditure of the general branch of the iron and steel industry and of research ratios for that branch are based on the information obtained in the course of the Board's 1955, 1959 and 1962 enquiries referred to in chapter 1 (paras. 4 and 7) above:

General Branch of the Iron and Steel Industry*

Year	Estimated expenditure on research	Estimated gross output	Estimated ratio of research expenditure to gross output
	£m.	£m.	per cent
1954–55	2·5	620	0·40
1958–59	4·0	860	0·46
1961–62	6·0	950	0·63

* The figures in the table refer to iron and steel products with which the Board are concerned. Where producers of iron and steel also engage in engineering and other activities with which the Board are not concerned, the figures have been apportioned. For this and other reasons the figures are only approximations. When they are being considered, the qualifications indicated in chapter 1 (paras. 10–13 above) should also be borne in mind. The figures obtained in the 1955 enquiry related to accounting periods of twelve months beginning at various dates in 1954 and ending on various dates in 1955; similarly for the 1959 and 1962 enquiries.

Although some allowance must be made for the fall in the value of money during the period from 1954–55 to 1961–62, the increase in the research expenditure of the general branch of the industry during that period clearly represented a substantial increase in the amount of resources applied to research. Both the expenditure on research and the research ratio increased more rapidly during the period of approximately three years from 1958–59 to 1961–62 than during the period of approximately four years from 1954–55 to 1958–59.

2. Of the estimated total of £4 million spent on research in 1958–59, some £3 million was spent by companies on research carried out in their own establishments; contributions to research associations, mainly to the British Iron and Steel Research Association (B.I.S.R.A.), accounted for about £¾ million, and payments to universities and other research organisations for about £¼ million. (Corresponding estimates are not available for 1961–62). As mentioned in

chapter 1 (para. 11) above, the estimate of expenditure by companies on research carried out in their own establishments probably does not cover all the expenditure of companies on experimental work carried out in the course of commercial production.

Research carried out by Companies in their own Establishments

3. The Board's 1959 enquiry showed, as might have been expected, a wide range of variation for different companies in the proportion of the amount spent by a company on research carried out in its own establishments to the company's gross output. The range was, in fact, from over 2 per cent of gross output to a negligible proportion. It appeared from the replies to the questionnaire that there were a number of companies that did practically no research for themselves. Some of these companies were small and understandably relied on research associations for their research requirements. Most of the larger companies whose replies to the questionnaire showed only a trifling expenditure on research do in fact undertake research on a significant scale; but, since most of their research had been carried out on works plant rather than in laboratories and the cost of such work had not been separately recorded, the expenditure of these companies on research was understated in their replies to the questionnaire. The Board were, however, concerned to find that one or two major companies were doing little if any research.

4. Most major steel companies have a central research department for fundamental and laboratory work and supplement the work of this central department by carrying out full-scale experiments on production plant. In some of these cases, works or branches of the company are served by research departments of their own as well as by the central laboratory. The decentralised research laboratories are usually engaged on *ad hoc* problems or in carrying forward and applying work done in the central laboratory; but in several cases they have also initiated major research projects.

5. The results of much of the research carried out by companies appear as improvements in existing processes of production. Although these improvements do not attract as much publicity as major inventions of new processes, they are cumulatively of great value.

6. A company that wishes to install a process developed elsewhere usually has to undertake some research in order to adapt the process to its own requirements; for example, the adaption to British requirements of the oxygen-converter processes for steelmaking, and of processes developed abroad for vacuum casting, has involved a considerable amount of research by the companies concerned. Companies are also carrying out an increasing amount of research in developing inventions made by B.I.S.R.A. and carrying them to the point of commercial application.

The British Iron and Steel Research Association

7. Since B.I.S.R.A. was formed, in 1944, to take over and expand the co-operative research previously undertaken by the Iron and Steel Industrial Research Council (para. 16 in chapter 2 above), the Association's resources have grown rapidly (see Figure 1 on page 13). The main item in the Association's industrial income is a block grant from the British Iron and Steel Federation

(£800,000 in 1962)*. Other industrial income is provided by the subscriptions of associate members (mainly manufacturers outside the steel industry, including plant manufacturers who have an interest in B.I.S.R.A.'s work) and of a few Commonwealth producers of iron and steel. The Association's grant from D.S.I.R. is at present at the rate of 15 per cent of grant-earning income within minimum and maximum limits. The "other income" of the Association shown in Figure 1 arises from investments, patent royalties, payments for special work for members, and other minor sources.

8. The block grant made by the British Iron and Steel Federation entitles all members of the Federation to belong to B.I.S.R.A. without further subscription. This gives B.I.S.R.A. an advantage over many other research associations who have to enlist the support of a large number of members individually and may thus be led to devote an unduly large proportion of their effort to the day-to-day problems of their members, with consequent detriment to longer-term research.

9. B.I.S.R.A. is controlled by a Council the majority of whose members are nominated by the British Iron and Steel Federation and The Iron and Steel Institute. The industrial members of the Council are usually general managers or directors of companies and the academic members are usually university professors. The other members of the Council include the Deputy Chairman of the Iron and Steel Board and the General Secretary of the trade union principally concerned with the industry.

10. B.I.S.R.A. is organised in divisions corresponding to the main groups of processes used in the industry and in departments working in basic sciences and providing services. There are at present five divisions, namely, Ironmaking, Steelmaking, Mechanical Working (e.g. rolling and forging), Plant Engineering and Energy, and Metallurgy. There was formerly a sixth division, for Steel Castings, but its work was taken over in 1950 by the British Steel Founders' Association (para. 19 in chapter 2 above). The departments include three for basic sciences, namely physics, chemistry, and operational research, and others for services to the industry such as development and information, and for services to users of iron and steel. For some important subjects, such as fuel efficiency, automation, and corrosion, there are not separate divisions or departments; but there are groups, within a division or department, responsible for such subjects.

11. The programme of research of each division is controlled by a panel of about twelve members drawn mainly from the senior managements of steelworks; the panels also include members of university staffs, scientists from other laboratories and, occasionally, members of the technical staff of the British Iron and Steel Federation and the Iron and Steel Board. The divisional panels are served by committees and sub-committees (whose composition is similar to that of the panels) and report to the Council of the Association. There are also a committee for finance and one for patents, both of which report to the Council.

12. The research programmes of the departments are determined partly by requests, received from the divisions, for basic scientific information and partly

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* The income of the Association shown in Figure 1 does not include special grants of £160,000 from the British Iron and Steel Federation and £80,000 from D.S.I.R., to meet the cost of new laboratories opened at Sheffield in November, 1963.

by the initiative of the departments themselves, or of the directing staff of the Association, in following up lines of work that are likely to be of use to the industry. The work of the Operational Research Department is, however, supervised by a panel reporting to the Council and served by two sub-committees.

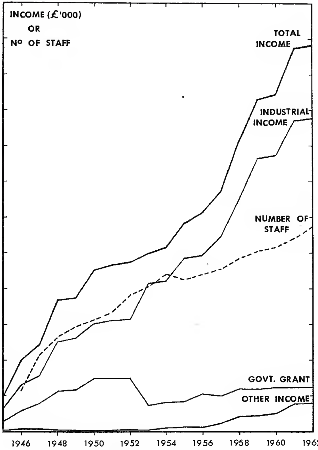
13. At the outset the Association had practically no laboratory facilities of its own (paras. 14 and 16 in chapter 2 above). At that time (1944) the provision of new buildings was difficult; but a laboratory was set up for the Physics Department in a converted factory at Battersea in 1946 and another for the coatings research of the Mechanical Working Division in a converted mansion at Swansea. Existing buildings were also acquired and adapted to provide laboratories for the rolling-mill section of the Mechanical Working Division at Sheffield, for the Steelmaking Division also at Sheffield, and for the Ironmaking Division at Normanby, Middlesbrough.* The site at Sheffield was large enough for permanent new laboratories to be built there. The first blocks were built in 1952–3 and formally opened by H.R.H. the Duke of Edinburgh in November, 1953; they included facilities for the Metallurgy Division. Later the Battersea laboratories were extended to accommodate the Plant Engineering and Energy Division and the Operational Research and Chemistry Departments; a few new buildings weie finished in 1959 and 1963, and further extensions are still in progress. The Sheffield laboratories are also now being extended and there are plans for developing a site for ironmaking research near the present facilities at Middlesbrough. One interesting feature at Sheffield is that part of the accommodation is used by the three small research associations that serve the spring, the file, and the cutlery industries. These associations have access to the library, canteen and other central services provided by B.I.S.R.A., and also benefit from scientific contacts with that Association.

14. The dispersion of the Association's laboratories has some administrative disadvantages and necessitates some duplication of services such as library and workshop facilities; but it has more than compensating advantages. The coatings research laboratory at Swansea is conveniently situated for the tinplate works in South Wales and is also within easy reach of several of the principal works making flat-rolled products. The main part of the Association's work on steelmaking, rolling and forging, and metallurgy is done at Sheffield, which is probably the best geographical centre for these divisions. The ironmaking laboratory near Middlesbrough is in one of the main ironmaking districts of the United Kingdom. The location of laboratories in ironmaking and steelmaking districts makes it easy for the staffs of the Association and of companies to get to know each other's work and for the Association to make effective contact with its members over a wide area. The laboratories working in basic sciences (physics, chemistry and operational research), and the head office, which are all in the London area, have easy access to central libraries and are conveniently situated for foreign contacts.

15. The Association also pays for specified research projects to be carried out at universities. These payments may take the form either of grants to university departments or of bursaries to research students. Occasionally, the Association has both taken part in, and contributed to the cost of, important research projects

* The Ironmaking Division also has laboratory facilities at the Imperial College of Science and Technology in London.

FIGURE 1—THE GROWTH OF B.I.S.R.A.



Years ended Dec. 31st.

abroad, for example the work at the International Flame Research Laboratory in Holland and at the experimental blast-furnace in Belgium (see paras. 35 and 36 in chapter 5 below). In addition to carrying out research, the Association organises each year a number of technical conferences at which woı ks' executives and technologists meet together with scientists to discuss the application of the results of research.

16. The administration of research through committees is sometimes criticised on the ground that it is likely to have a deadening or frustrating effect on the scientific staff. In B.I.S.R.A., however, it has been remarkably successful. Because the majority of committee members are works' executives, the research programme is adapted to the practical needs of the industry. Through their membership of the committees, works' executives keep so closely in touch with research that preliminary trials at works can often be started without waiting for a research project to be finished and reported. Moreover, when a research project is completed there will be several works' executives who are thoroughly familiar with its history. The committees encourage the really novel ideas that probably come more often from scientists on the Association's staff or outside the industry than from the industry itself, and have shown themselves ready to support any line of work that looks reasonably promising.

17. Perhaps the main drawback to the Association's present system of administration is that, with over 500 committee members each interested in particular problems, the number of projects in hand tends to be too high. The present number, which is about 200, is excessive for the resources available, with the result that the Association's effort is too dispersed. Either the Association should reduce the number of projects so that more resources can be applied to those of the greatest potential value to the industry, or the Association's resources should be increased so that more adequate attention can be given to all projects that are approved.

18. The Association's procedure for the allocation of funds begins with the submission by each of the divisional and departmental committees of an estimate of the expenditure that will be needed, in the year, for the most urgent problems in the committee's field. Each divisional panel brings the estimates of its committees together and, after considering priorities, adjusts the total to what the panel regards as a reasonable request to make to the Council. By a similar process the Finance Committee and the Council itself adjust the estimates as a whole to bring them within the resources available. A margin is retained for urgent problems that may arise at short notice.

Other Research Associations

19. Although B.I.S.R.A.'s work is entirely devoted to serving the iron and steel industry and users of iron and steel, there are other research associations whose work is of interest to the general branch of the industry. A fair proportion of the work of the British Cast Iron Research Association (B.C.I.R.A.) and of the British Steel Castings Research Association (B.S.C.R.A.) falls into this category; these two associations are dealt with in some detail in chapter 4 (paras. 3–6 and 7–10) below. Of other research associations, the British Coke Research Association and the British Ceramic Research Association have the greatest interest for the steel industry. Because of the work of the first of these associations, it is unnecessary for B.I.S.R.A. to do much work on coke; and the

interests of the steel industry in coke are looked after by a joint committee of the two Associations. The British Ceramic Research Association carries out research on refractories for the iron and steel industry and receives a grant from B.I.S.R.A.; in this case also, there are joint committees of the two Associations to supervise the work. Both the British Coke Research Association and the British Ceramic Research Association receive some of their income directly from the iron and steel industry because many producers of iron and steel are members of these Associations (or of the parent trade associations). Other research associations whose work is of interest to the iron and steel industry are the:—

British Coal Utilisation Research Association
British Electrical and Allied Industries Research Association
British Glass Industry Research Association
British Non-Ferrous Metals Research Association
British Ship Research Association
British Welding Research Association
Cutlery and Allied Trades Research Association
Drop Forging Research Association
File Research Council
Spring Manufacturers Research Association

The interest of the iron and steel industry in these associations will be evident in most cases from their titles. The industry is interested in the work of the British Glass Industry Research Association because some problems of furnace design connected with glass-melting tanks are very similar to problems connected with open-hearth steel-melting furnaces, and also because the chemical constitution of glass has some relation to that of slags.

20. Research associations co-operate on subjects of common interest. In addition to the joint committees mentioned in para. 19 above, B.C.I.R.A. and B.I.S.R.A. have a joint research project on factors governing the life of ingot moulds; and B.S.C.R.A. and B.I.S.R.A. collaborate in studying the hot strength of steel as it affects the cracking of ingots and of castings, and in studying jet techniques for degassing steel.

The Iron and Steel Institute

21. Although The Iron and Steel Institute ceased to have any direct activities in research when B.I.S.R.A. was formed in 1944 (para. 16 in chapter 2 above), it retained and still has an important role as a scientific society. It is not a qualifying institution conferring diplomas or their equivalent; but otherwise it has a wide range of functions of the kind usually performed by scientific societies. It is used both by the industry and by B.I.S.R.A. as the main channel for the discussion and publication of research; its Journal, published monthly, has an international reputation. Two general meetings are held each year in London; and in most years special meetings are held in ironmaking and steelmaking centres in this country and abroad. Parties of members visited steelworks in the U.S.A. and Canada in 1961, works in Germany in 1962, and works in India and Japan in 1963. In this way the Institute is a valuable source of international contacts, particularly in matters of research; any British company wanting the best source of information on any aspect of foreign practice can usually find it through the Institute. The Institute has specialist groups for works engineering

and for powder metallurgy, and through the Institute of Metals maintains close contact with developments in non-ferrous metallurgy. The Institute encourages students and others by the award of medals and prizes that are highly esteemed. The Institute's main sources of income are the subscriptions of its members and the revenue from its publications. Most companies encourage members of their staffs to join the Institute in appropriate cases and also make grants to the Institute from time to time. There are also local institutes, affiliated to the central body, in most ironmaking and steelmaking districts. These institutes hold meetings to discuss local problems, sometimes with speakers from other districts, and provide focal points for interest in iron and steel technology. They are particularly valuable in stimulating junior works staff, and others who do not often have the opportunity of taking part in meetings at a distance from their own centres, to take an interest in research and its methods.

Chapter 4

The Research Arrangements of the Ironfounding and Steelfounding Branches of the Industry

1. The Board's 1959 enquiry (para. 7 in chapter 1 above) showed that nearly half the research of the ironfounding and steelfounding branches of the industry was being carried out by the British Cast Iron Research Association (B.C.I.R.A.) and the British Steel Castings Research Association (B.S.C.R.A.). The proportion of genuine research for which these Associations are responsible is probably larger than half because a considerable part of the expenditure shown by companies in their replies to the questionnaire related to routine and service investigations. The two Associations collaborate in fields of common interest, for example in research on moulding materials, and both collaborate with the British Iron and Steel Research Association (B.I.S.R.A.).

Research carried out by Companies in their own Establishments

2. Although a large part of the research in the ironfounding and steelfounding branches of the industry is done by the two research associations, some foundries do a significant amount of research in connection with their own products. For example, although nodular iron was developed in the first instance by B.C.I.R.A., the considerable technical problems that arose in the production of pipes from this material were solved by the manufacturer concerned. Companies also undertake research to solve their own special problems arising, for example, from the requirements of the Clean Air Act. Many foundries are branches of large steelmaking or engineering concerns. In these cases the research requirements of the foundry are often dealt with by a central research department in the parent concern; this is particularly the case in steelfounding, where the metallurgical problems are more severe than in ironfouuding. In the case of cast iron, a fair amount of research is also carried out by users, for example by motor manufacturers on special irons required for motor-car components.

The British Cast Iron Research Association

3. The aims of B.C.I.R.A. are to find means of improving the quality of cast iron, facilitating its manufacture, and extending its uses. Because the ironfounding industry includes a large number of small companies that cannot support research laboratories of their own, the provision of an advisory service to members takes up a large part of the Association's resources. The Association also undertakes special items of research for members in return for fees.

4. As has already been mentioned (para. 18 in chapter 2 above), B.C.I.R.A. is one of the oldest research associations, having been incorporated in 1921. The Association opened its first laboratories in 1924. In 1927 it moved to larger

(88789) A** 2

premises in Birmingham, and remained there till 1942 when it moved to Bordesley Hall, Alvechurch, some fifteen miles from Birmingham. The grounds of Bordesley Hall provided ample room for extensions of the laboratories when new building became possible after the war. In addition to Bordesley Hall, there is a laboratory at Blantyre, near Glasgow, to serve the Association's members in Scotland. Between 1921 and 1945, the total income of the Association rose from £5,000 to £33,000 a year, and its staff grew from 3 to 68. The subsequent growth of the Association's resources is shown in Fig. 2 on page 19.

5. The Association's industrial income is largely provided by the Joint Iron Council from the proceeds of a voluntary levy on foundry pig-iron. This source of income is supplemented by subscriptions from members who wish to use the Association's advisory service; the rate of subscription is related to the wages bill of the member. The members that take the Association's advisory service account for the major part of the output of the industry. Membership of the Association is also open to suppliers of plant, equipment and materials for foundries, and to users of iron castings. The Association also has numerous Commonwealth members. The Association receives a Government grant through D.S.I.R. In the year 1962–63 the total income of the Association was £271,000 (made up of £167,000 from industry, £74,000 from the D.S.I.R. grant and £30,000 from miscellaneous sources) and the staff numbered about 170.

6. B.C.I.R.A. is controlled by a Council elected by the members of the Association. The Council has a group of specialist committees and sub-committees, each of which meets about four times a year to consider the progress of research and to review the programme. Members thus have the opportunity of suggesting subjects for investigation and of deciding when investigations should be terminated. The Association's staff are, however, allowed considerable freedom in the initiation of new lines of research.

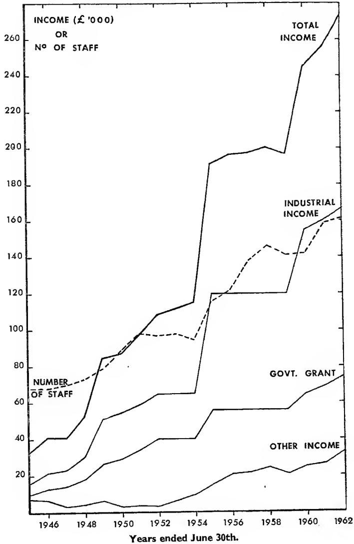
British Steel Castings Research Association

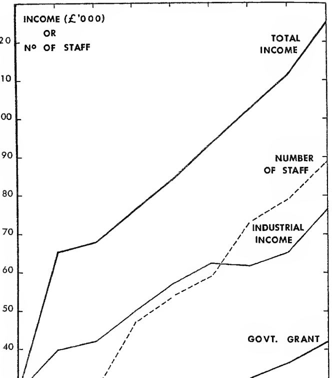
7. This is the youngest of the three research associations serving the iron and steel industry, having been incorporated in 1953 to take over the activities of the Research and Development Division of the British Steel Founders' Association (para. 19 in chapter 2 above). The growth of the Association's resources is shown in Fig. 3 on page 20. Although there are many differences between the technical problems arising in steelfounding and in ironfounding, there are basic similarities; and the pattern of the activities of B.S.C.R.A. is similar to that of B.C.I.R.A.

8. The present laboratories of B.S.C.R.A. in Sheffield were opened in June, 1957, and have since been extended. They include laboratories for the chemical, physical and metallurgical examination of raw materials and of cast steel, a laboratory for plant engineering studies, and a laboratory for research on foundry atmospheres and on dangers to health arising from dust and noise. There is also an experimental foundry with melting furnaces and with facilities for moulding and for heat-treatment.

9. In the year 1962–63 B.S.C.R.A. had a total income of £128,000 (made up of £78,500 from the steelfounding and other industries, a grant of £39,500 from D.S.I.R., and £10,000 from miscellaneous minor sources) and a staff of about 95. Unlike B.I.S.R.A. and B.C.I.R.A., B.S.C.R.A. is not supported by a block

FIGURE 2—THE GROWTH OF B.C.I.R.A.




INCOME (£'000)
OR
N° OF STAFF
TOTAL INCOME
NUMBER OF STAFF
INDUSTRIAL INCOME
GOVT. GRANT
OTHER INCOME
120
110
100
90
80
70
60
50
40
30
20
10
1954
1955
1956
1957
1958
1959
1960
1961
1962
Years ended March 31st.

grant from a trade association, but depends mainly on subscriptions paid by members individually. The rate of subscription is related to the amount of the wages bill of the member, subject to a minimum of £250 a year. The Association's membership accounts for about three-quarters (by weight) of the output of the steelfounding industry.

10. The Association has received special assistance from D.S.I.R. for work directed to showing members how the results of research can be applied. All members are regularly visited by the Association's staff and the Association holds conferences and training courses for the staffs of members.

Institute of British Foundrymen

11. This institute undertakes for the foundry branches of the industry functions similar to those undertaken by The Iron and Steel Institute for the general branch of the industry (para. 21 in chapter 3 above). It arranges technical conferences and visits to works and participates in an international foundry congress which is held annually. In addition, the Institute, through its Technical Council, organises applied research in which research associations very often collaborate. The Joint Iron Council makes a substantial contribution towards the administrative expenses of the Technical Council.

Chapter 5

Arrangements for Iron and Steel Research in other Countries

1. There is probably a greater international exchange of scientific and technical information in the iron and steel industry than in any other industry. Members of the technical staffs of companies frequently visit works in other countries, and there are numerous international conferences on the technology of iron and steel. In most countries, both companies and central institutions associated with ferrous metallurgy show a remarkably liberal attitude to publication in scientific journals. Through an efficient service of abstracts and translations, organised by The Iron and Steel Institute, the British iron and steel industry is well informed about technical progress in all parts of the world. Many British companies have agreements for exchanging information with foreign companies operating in similar fields.

2. Comprehensive information is not available as to the extent of the resources applied to research in iron and steel in other countries. Estimates for some countries are given in this chapter; but caution should be exercised in any attempt to use these figures as a means of comparing the research effort of the iron and steel industries in other countries and in Britain. It has been pointed out in chapter 1 (paras. 10 and 11) above that it is not possible to make entirely comparable estimates of the research efforts of industries of different kinds in this country. Estimates of the research efforts of the iron and steel industries in different countries must be similarly qualified.

France

3. There is little information about the scale of the research carried out by French iron and steel companies in their own works. Results of investigations in which companies have taken part are published in French metallurgical journals; but it is usually not clear whether the work has been done entirely by companies or whether the central research association or academic institutions have assisted in it. Much of the research carried out by companies is probably routine study on quality control and " trouble-shooting ". Some work, however, is done on the development of new processes; for example, the Société des Aciéries de Pompey near Metz has carried out a considerable amount of research on the injection of oil into blast-furnaces.

4. France has a strong central research association, the Institut de Recherches de la Sidérurgie (I.R.S.I.D.), which was founded in 1944 and came into effective operation in 1946. I.R.S.I.D. is similar in many ways to the British Iron and Steel Research Association (B.I.S.R.A.); it has its own laboratories and is

closely connected with the industry. The headquarters of I.R.S.I.D. are at St. Germain-en-Laye, near Paris, together with laboratories for metallurgy, for rolling-mill work and for several scientific departments. There is also a pilot-plant laboratory at Maizières-lès-Metz in Lorraine; this includes a branch dealing with the preparation of ore and with ironmaking, and another dealing with steelmaking. The steelmaking branch was associated with the development of the OLP process (para. 39 in chapter 6 below).

5. At the beginning of 1963, the expenditure of I.R.S.I.D. was at the rate of approximately 35 million francs (£2·7 million) a year and the total staff was about 670 of whom about 400 were at St. Germain and 270 at Maizières-lès-Metz.* I.R.S.I.D. is financed mainly by a voluntary levy paid by steel companies and based on their sales; there is no Government grant. I.R.S.I.D. has many links with academic institutions working in metallurgy and collaborates with these institutions in research work of interest to the iron and steel industry. It is administered by a board of directors who are appointed by the Chambre Syndicale de la Sidérurgie Française and are drawn from the managements of iron and steel companies. In addition to research on the production of iron and steel, I.R.S.I.D. will also undertake, at the request of the iron and steel industry, work for Government departments and other users of iron and steel, for example research on material for the French Railways.

6. Foundry research is separated in France, as in Britain, from research for the general branch of the steel industry; but whereas in Britain there are separate research associations for ironfounding and for steelfounding (para. 1 in chapter 4 above), in France research in both ironfounding and steelfounding is carried out by one organisation, the Centre Technique des Industries de la Fonderie, whose central laboratories are at Sevres near Paris. This body also serves non-ferrous foundries. It is financed by a statutory levy on turnover. It was formed in embryo in 1942 and established in 1945; the central laboratories at Sevres were opened in 1952. There are also regional laboratories from which metal-founders can obtain expert advice. The total expenditure is believed to be about 10 million francs (£800,000) a year; it is not known how much of this goes towards work on ferrous casting. The total staff numbers about 300 of whom about 100 have full technical qualifications.

Belgium, Luxembourg and the Netherlands

7. There is a central research organisation known as the Centre National de Recherches Métallurgiques (C.N.R.M.) which is administered mainly by the steel industries of the three Benelux countries and financed by those industries and the Belgian Government. No information is available as to how much the industries in Belgium, Luxembourg and the Netherlands spend on research in addition to their contributions to C.N.R.M.

8. From 1946 until 1960, C.N.R.M. operated in two main divisions—the Liège division concerned mainly with fundamental research in metallurgy, chemistry and physics and with ironmaking and steelmaking, and the Hainaut division, at Charleroi, concerned with research on continuous casting. In both cases, the buildings were located in the University campus; the staff were thus enabled to

* I.R.S.I.D.'s expenditure is nearly three times that of B.I.S.R.A. although its staff is only about 17 per cent larger. The reason for the difference between these ratios is probably that research on a pilot-plant scale, which is costly in equipment and materials, is done to a much greater extent by I.R.S.I.D. than by B.I.S.R.A.

keep in touch with academic work. In 1960, all the work of C.N.R.M. was concentrated at Liège. C.N.R.M. is closely associated with the international blast-furnace research that is carried on near Liège (para. 36 below) and has joined with B.I.S.R.A. in research on continuous casting (para. 55 in Chapter 6). Much of C.N.R.M.'s applied research is carried out at producers' works. In 1962 the total expenditure of C.N.R.M. was at the rate of about 80,000,000 Bel. frs. (£570,000) a year and the staff numbered about 230. One of the best known developments with which C.N.R.M. has been associated is the LDAC process (para. 39 in chapter 6 below).

West Germany

9. In West Germany, central research is organised through the German steelmakers' technical association, the Verein Deutscher Eisenhüttenleute (V.D.E.) which has power to institute financial levies on the steel industry. V.D.E. has research committees similar to those of B.I.S.R.A. (para. 11 in chapter 3 above). It provides funds for research carried out by the Max Planck Institute for Iron Research in Düsseldorf, which is the major institution engaged in central research. V.D.E. also makes grants to universities and other academic institutions carrying out research in iron and steel.

10. The Max Planck Institute has a staff of about 280, of whom about 60 are science graduates, and is mainly concerned with fundamental work. Its expenditure is about £450,000 a year; of this some £270,000 comes from V.D.E., £90,000 from the provincial Government and £90,000 from local iron and steel companies and other sources.

11. The major academic institution working on iron and steel is the Technische Hochschule at Aachen, which has 10,000 students and is the largest centre in Germany for training iron and steel technologists. It carries out fundamental research and also has extensive pilot-plant facilities for ferrous metallurgy and foundry work. The research at Aachen is financed partly by V.D.E. and partly by the West German Government.

12. The expenditure of the German steel industry on research in companies' works must be considerable. This is evident (although figures are not available) from the extent to which research is carried out on full-scale production plant. Well known examples of the results of such research are the processes developed by several German companies for casting large forging-ingots *in vacuo* and the Rotor process for steelmaking developed by Hüttenwerk Oberhausen. The German industry also developed the Krupp-Renn process for making iron from low-grade ore (para. 4 in chapter 6 below). A considerable amount of full-scale research must also have been carried out in connection with the installation of continuous casting on a commercial scale in several works.

Sweden

13. The Swedish central iron and steel institute in Stockholm—Jernkontoret—combines the functions of a trade association, a scientific society, and a body for organising collaborative research. It sponsors a considerable amount of laboratory research in the Metallographic Institute at the University of Stockholm and of collaborative research carried out in steelworks. Jernkontoret has at present no laboratories of its own, but there are plans for a pilot-plant laboratory at Norrbotten in the north of Sweden.

14. The amount of research carried out by companies individually is also considerable; the extent of this work is probably due in part to the fact that a high proportion of Swedish steel consists of special qualities. The development of the Kaldo steelmaking process (para. 40 in chapter 6 below) is a particularly interesting example of the research carried out by companies; it also illustrates the value of pilot-plant research.

Other Countries in Western Europe

15. In the remaining countries of Western Europe except Italy, the steel industries consist of only one or a small number of companies, so that the question of co-operation in research hardly arises. The Italian steel industry includes a number of small companies and there is a move towards an institution for co-operative research. Major works, such as those of the Finsider company in Italy, have their own large research departments. The Austrian steel industry, though relatively small, has major researches to its credit; the outstanding example is the development of the LD process for steelmaking (para. 38 in chapter 6 below).

The European Coal and Steel Community

16. The European Coal and Steel Community (E.C.S.C.) has substantial activities in research that are additional to the activities of its member countries. The E.C.S.C. Treaty lays on the High Authority the duty of encouraging technical and economic research in connection with the production of coal and steel and with the development of markets for coal and steel; and also the duty of organising contacts between the research organisations concerned in the member countries of the Community. The Treaty further provides that the High Authority (after consulting the E.C.S.C. Consultative Committee) may initiate and facilitate research by encouraging producers to finance research jointly, by allocating grants which the High Authority may receive, or by allocating funds obtained by the High Authority through the general levy on coal and steel production. The research budget is administered by the High Authority which is advised by a Technical Research Committee composed of representatives of the member countries. (Meetings of the Committee are attended by an observer from the United Kingdom.) The High Authority may assist research by producers, by research institutions and, if circumstances warrant, by individuals; but financial aid derived from the general levy is subject to the approval of the E.C.S.C. Council of Ministers. To qualify for financial aid, a research project must be of wide interest within the Community; and, in general, the High Authority will not bear the full cost although it may contribute as much as 90 per cent.

17. The funds made available by the High Authority are considerable. In the ten years from 1953 to 1962, the High Authority entered into commitments amounting to about £3·6 million* for research in iron and steel. The High Authority also agreed in principle, in June, 1961, to set aside an amount of about £1·8 million for work on automation in the production of iron and steel; but not all of this amount may yet have been allocated to projects. Assistance has also been given to a wide range of researches from the preparation of ore to rolling and metallography. The results of researches which the High Authority helps to finance are made available to all interested parties in the Community.

* Exclusive of expenditure on prospecting for new sources of ore, which also forms part of the High Authority's research budget.

Eastern European Countries*

18. In Czechoslovakia the iron and steel research institute had, in 1960, a staff of about 300 located in various buildings in Prague. A new building was being erected to replace these facilities, and was expected to be ready in 1963. There is also a refractories research institute concentrating on practical problems; its staff numbered about 65 in 1960 and was then expected to increase to about 130 by 1965. In Yugoslavia there is, at Ljubljana, a metallurgical institute that was formerly part of the university faculty of mining and metallurgy, but is now a separate body supported by the Yugoslav Iron and Steel Federation with some financial aid from the Government. It is nominally a general metallurgical institute, but some 80 per cent of its work is devoted to iron and steel. It had in 1960 a staff of about 120. One Yugoslav steelworks operates an experimental blast-furnace with an output of some 65 tons of iron a day. In Poland the Iron and Steel Research Institute at Gliwice, which is financed by the Ministry of Heavy Industry, had in 1957 a staff of about 500. The facilities at these various research institutes are such as would be expected and are similar to those of corresponding institutions in Western Europe.

U.S.S.R.†

19. Much of the iron and steel research in the U.S.S.R. is carried out in the Central Scientific Institute of Ferrous Metallurgy, which is responsible to the State Planning Commission (Gosplan). The Institute has a central research laboratory in Moscow, and an experimental steelworks, provided with large pilot-plant facilities, at Nova Tula some 110 miles from Moscow. The staff of the Institute numbered about 2,500 in 1958, but is now probably larger. In addition to the Central Institute, there are branch institutes in some of the provincial steelmaking centres; these branches are largely concerned with local problems. Another important institute, the Baikov Institute of Metallurgy, is concerned principally with fundamental work and is part of the U.S.S.R. Academy of Sciences.

20. In the U.S.S.R., automation is regarded as a sufficiently important field to justify a separate laboratory, the Central Laboratory for Automation, which had in 1958 a staff of about 500. This institution deals with both automation and instrumentation, and naturally has close links with the Central Scientific Institute of Ferrous Metallurgy.

21. Although there are these central institutions, it seems to be the policy of the Soviet Government to give other organisations considerable freedom to develop their own ideas. It also seems, from Soviet technical journals, that works are encouraged themselves to undertake research directed towards the solution of their special problems and the improvement of methods of production.

22. The development of steelworks in the U.S.S.R. is handled by a Government institute for the design of metallurgical works (Gipromez) which specifies the optimum capacities and designs for various items of plant. It is to be presumed that Gipromez keeps in close touch with the Central Scientific Institute of Ferrous Metallurgy and that the results of research are thus quickly

* Para. 18 is based mainly on the reports of British delegations that visited Czechoslovakia and Yugoslavia in 1960, and Poland in 1957.

† Paras. 19–25 are based mainly on the report of a British delegation that visited the U.S.S.R. in 1958.

put into practice. The new oxygen-converter processes for steelmaking seem, however, to have been neglected until recently in Russia; this is probably because advanced designs of open-hearth furnaces have been standardised. Rapid progress in LD steelmaking is now planned.

23. Foundry research is handled by separate organisations in the U.S.S.R. as in Britain. The main institutes are the Central Research Institute of Technology and Machine Building, and the Scientific Research Institute for Foundry Machinery and Foundry Technology. Post-graduate departments of technical universities also carry out a substantial amount of foundry research.

24. The impression gained by the British delegation that visited the U.S.S.R. in 1958 was that the expenditure of the Central Scientific Institute of Ferrous Metallurgy alone was about the same as the total expenditure on iron and steel research in Britain, and that the total expenditure on iron and steel research in the U.S.S.R. was about three times as large. The output of iron and steel in the U.S.S.R. is approximately three times the output in Britain.

25. From the results that have been published, it seems that the achievements of research on iron and steel in the U.S.S.R. have been more in the direction of improving established processes than of inventing new processes. In blast-furnace practice in the U.S.S.R. notable advances have been made in securing high rates of output by the use of well-prepared burdens, high top-pressures, and high driving-rates. Furnaces are well instrumented and deviations from smooth running in any part of the furnace are immediately detected and corrected. Similarly, Russian open-hearth furnaces are large in size and of advanced, though still conventional, design; fast driving-rates are attained with the aid of oxygen. The Russian industry does not appear to have made great advances in the techniques of rolling and has been led by a shortage of capacity for rolling to concentrate on continuous casting. A British delegation, which visited the U.S.S.R. in 1959 to study continuous casting, reported that about a dozen plants were operating or in course of construction. Some of these appeared to be experimental or pilot-scale plants, but others were on a full scale for commercial production. With the exception of one designed for inclined casting, the plants were of the conventional vertical pattern. There have been reports of research on the continuous casting of cast-iron sheet.

U.S.A.

26. In the U.S.A. anti-trust legislation has had the effect of discouraging co-operation in industrial research and until recently there have been no co-operative research associations. There is, nevertheless, an extensive exchange of technical, as distinct from commercial, information. The American Iron and Steel Institute publishes information about the designs and capacities of plants, and there is some exchange of information on plant performance. There are also many conferences at which technical progress is discussed. Most of the research undertaken by the U.S. steel industry is, however, carried out by companies individually.

27. Until about ten years ago the research effort of the U.S. iron and steel industry was small in relation to the size of the industry. It was customary for users to specify special requirements on the basis of their own research into the

properties of iron and steel. Because producers in the U.S.A. had the advantage of supplies of pure raw materials and cheap fuel, they had less incentive than producers in some other countries to undertake research on the production of common steels. The position has since changed; most of the major producers in the U.S.A. now undertake research on a large scale.

28. The largest producers, the U.S. Steel Corporation, have a central research establishment near Pittsburgh with separate divisions for fundamental and applied research. The laboratories for fundamental research are equipped with almost every conceivable facility for their work; the applied research laboratories have a wide range of facilities including pilot-plant facilities for blast-furnace research, steel-melting facilities, small rolling-mills, plant for coating (e.g. enamelling, tinning, and electroplating), and digital and analogue computers. Facilities for research on blast-furnaces were recently much extended by the provision of a 4-ft. blast-furnace on a nearby site. Steelmaking research that cannot be undertaken at the Pittsburgh site owing to difficulties in connection with the supply of molten metal, atmospheric pollution, etc. is carried out at the Company's South Works near Chicago, where the facilities include an 8-ton oxygen-converter unit. The total staff employed by the U.S. Steel Corporation on research numbers about 1,500.

29. The Bethlehem Steel Company have recently opened, at Bethlehem, new central research laboratories well equipped for both laboratory and pilot-plant work. The staff numbered about 500 when these laboratories were opened in 1961; it is expected to grow eventually to about 900. Other major American companies that have central research laboratories include the Jones and Laughlin Steel Co. at Pittsburgh, the Inland Steel Co. near Chicago, National Steel at Weirton near Pittsburgh, and the Republic Steel Corporation at Cleveland.

30. In addition to the research facilities that American steel companies are increasingly providing, the U.S. Government (Bureau of Mines) has for a number of years provided facilities at an experimental blast-furnace at Pittsburgh. This furnace was originally built for research on scarce raw materials, e.g. recovering manganese from slags; it was used by the U.S. Steel Corporation before their own furnace was built, and has also been used by oil companies experimenting with oil injection. A large amount of research on alloy steels is carried out by the Union Carbide Metals Co. with the object of enlarging the market for alloying materials.

31. It seems probable that the ratio of research effort to output is much greater in the U.S.A. than in the British iron and steel industry; but, since there is virtually no co-operative research in the U.S.A., there is likely to be a good deal of expensive duplication of work. There have recently been some moves towards co-operative research; in particular, twenty-two companies have formed a research association to use the facilities at the experimental blast-furnace belonging to the Bureau of Mines. Since the U.S. Government is a partner in this association, there is no risk of an infringement of the anti-trust laws. There is also some co-operative research in the American steelfounding industry through the Steel Founders' Society of America. The Society has a research director and staff but no laboratories; it proceeds by sponsoring projects in universities and research institutes.

32. For industrial research in the U.S.A., organisations that undertake research on a commercial basis are extensively used. The client pays a fee and the results of the research are confidential to him; he also receives the rights in any consequential patents. One example of the work done by such organisations in the field of iron and steel is an assessment, commissioned by the electricity supply industry, of the economic prospects for electric steelmaking. Some of the American research organisations have opened branches in Europe.

India

33. Central research on iron and steel is carried out by the National Metallurgical Laboratory, Jamshedpur, which is administered by the Council of Scientific and Industrial Research at Delhi. This laboratory deals with metallurgy generally; but much of its work is concerned with iron and steel and the formation of separate divisions for ferrous metallurgy has recently been approved. Its facilities for pilot-plant research include a low-shaft blast-furnace, a plant with a capacity of 10 cwts. an hour for enriching ores, and a plant for coating steel with aluminium.

Japan

34. The Japanese iron and steel industry has greatly increased its research facilities in recent years. There is no co-operative research association comparable to B.I.S.R.A. but most of the major steelmaking companies have their own central research laboratories. Examples from the two largest companies are the new central research laboratories of the Yawata Iron and Steel Co. Ltd. in Tokyo which cost £1·4 million and employ 350 people (of whom 100 are graduates), and those of the Fuji Iron and Steel Co. Ltd., also in Tokyo, which cost £1·3 million and employ about 250 people (of whom about 75 are graduates or equivalent). Both these laboratories are remarkably well equipped with advanced scientific instruments and with pilot-plant facilities. Both companies also employ in research departments in their works about twice as many people as are found in their central laboratories; but much of the work carried out in the decentralised research departments is doubtless routine. The total research expenditure of the Japanese steel industry now amounts to about £8·5 million a year, i.e. to about 0·85 per cent of the industry's turnover. In addition, the Government operates a National Research Institute for Metals in Tokyo which spends nearly £1 million a year and employs just over 400 people (of whom 150 are graduates). The Institute is concerned with metallurgy generally, but most of its effort has until now been devoted to iron and steel.

International Research Projects

35. The arrangements of the European Coal and Steel Community for financial aid to research have been referred to in para. 16 above. There are other instances of international collaboration in major research projects, and in some cases the United Kingdom has taken part. The arrangement of longest standing is the International Flame Research project started in 1949. The purpose of this project is to study flame properties such as temperature and emissivity, and so to improve the performance of high-temperature furnaces. The facilities, which include experimental furnaces well equipped with instruments, are at the Royal Dutch Steelworks at Ijmuiden in Holland; the programme is administered by a Foundation composed of representatives of the

countries and organisations tbat support the project. Tbe organisations concerned include E.C.S.C. whicb contributes 35 per cent of the income of the Foundation. The countries principally concerned at present are Belgium, France, Germany, Holland, the United Kingdom, and tbe U.S.A. These countries bave representatives on the Foundation and on its research panels; there are also committees in eacb subscribing country. Switzerland and Finland pay small subscriptions as associate members of tbe Foundation, but are not represented on its committees. The total income of the Foundation for 1962 was about £61,000 of whicb about £9,700 was contributed from the United Kingdom. The British contribution was made by B.I.S.R.A., by some steelmaking companies, and by other industries interested in problems of combustion. In addition to producing much useful scientific information, this project was one of the first to sbow that industrial research could be successfully carried out by a team of scientists of different nationalities.

36. Work done at an experimental blast-furnace near Liège provides another example of international researcb. This project is one of those in receipt of financial aid from E.C.S.C. (para. 16 above) but five European countries also at present contribute to it, either financially or by providing staff.

37. From 1958 to 1960 B.I.S.R.A. and C.N.R.M. collaborated in continuous casting at a Belgian steelworks. Research workers from Britain and Belgium worked on a pilot-plant supplied with steel from the ordinary production of the works and solved many of the problems associated with the continuous casting of rimming steel.

38. The U.S. Steel Corporation and B.I.S.R.A. have collaborated in mathematical analysis of factors governing tbe efficiency of blast-furnace stoves. The Australian steel industry has taken a close interest in some aspects of B.I.S.R.A.'s blast-furnace research and has sent staff to work on one of the Association's projects.

Summary

39. In many other countries, as in Britain, industrial researcb in iron and steel is carried out partly by central institutions financed by the industry, often with Government support, and partly by companies individually. Tbe proportion of researcb carried out by central institutions varies. In Britain, for example, companies in the general branch of the industry spend about three times as mucb on their own research as is spent by the industry's research association; the situation in Germany is probably similar. In France and Belgium, on the other hand, the central institutions are responsible for much higber proportions of the research; and in tbe U.S.S.R. and the other countries of Eastern Europe the central institutions play a paramount part. In the U.S.A. and in Japan tbere is not mucb co-operative researcb; most of the work is undertaken by individual companies either directly or (in the case of tbe U.S.A.) through research organisations operating on a commercial basis.

40. At the time of the Board's 1959 enquiry as to the size of the researcb effort of the British industry, the Board also sought information as to the size of the researcb efforts of iron and steel industries in other countries. The information that could be obtained, either from published sources or by private enquiry, was not sufficient, or reliable enougb, for the Board to be able to draw any firm conclusions. There was, bowever, some evidence tbat at tbat time the

expenditure of the French and U.S. industries on research was rather more than 1 per cent of their gross outputs. The corresponding proportion for the British industry was about 0·46 per cent in 1959; although it had increased to about 0·63 per cent by 1962, it was probably still considerably lower than the proportions in France and the U.S.A. and also in Japan.

Chapter 6

Progress and Achievements in Research on Iron and Steel

1. This chapter describes in outline the main technical advances that have taken place in this country since the war in the principal processes used in the manufacture of iron and steel, and the part played by research in these advances; it also refers to some of the more notable technical advances in Europe and America. A comparison of technical progress here and abroad is helpful in considering whether sufficient research has hitherto been done in this country and whether (and if so in which directions) a greater research effort is now called for.

THE PREPARATION OF ORE

2. There are still many blast-furnaces where some or even all of the ore is charged without preparation; but a blast-furnace works more efficiently if the ore, limestone and coke are charged in evenly sized lumps and are free from fine particles which make the burden less permeable and impede an even distribution of the blast and of the reacting gases. In addition, the ore should be rich in iron; but a burden which included none but very rich ore would be unsuitable in most cases for British practice, because it would not provide sufficient slag to take up the sulphur introduced by the coke.

3. Much of the research on the preparation of ore has consequently been concerned with:

(*a*) concentrating and blending lean ores;

(*b*) crushing and screening ores to the desired size; and

(*c*) agglomerating fine ores.

4. After the war it was feared that there would be a serious shortage of high-grade ores throughout the world; much research on concentrating low-grade ores was therefore carried out in countries with reserves of such ores. In France research on the dressing of minerals occupies an important section of the pilot-plant laboratory of the Institut de Recherches de la Sidérurgie at Maizières-lès-Metz (para. 4 in chapter 5 above) and progress has been made with the concentration of low-grade ores from Lorraine and other parts of France. In Germany attention has been directed mainly to a rotary-kiln process (the Krupp-Renn process) for producing from low-grade ores nodules of rather impure iron that can be used to enrich the blast-furnace burden. In the event, the expected shortage of rich ores did not come about because new deposits were discovered, and some Krupp-Renn plants have consequently been closed. Many of the countries with reserves of rich ore also have large deposits of leaner ores in which silica is the main impurity; the silica is sometimes in such a form that it cannot readily be removed by the usual methods of mineral-dressing. The

improvement of processes for removing silica from these leaner ores is thus another subject for research.

5. About one-third of the iron made in the United Kingdom comes from low-grade ores having an iron content of from 18 to 30 per cent. The concentration of such ores is thus clearly an important subject for research, and much work has been done on it both by the British Iron and Steel Research Association (B.I.S.R.A.) and by companies in the industry. The usual methods of mineral-dressing, which depend largely on separation by physical processes, do not work with most of the lean ores found in the United Kingdom because of the close chemical bonds between the iron oxide and the silica and other non-ferrous constituents. A limited success can be achieved with ore from some areas but the amount of such ore is small. The United Steel Companies Limited have developed at their Appleby-Frodingham branch a very elegant chemical process in which hydrochloric acid gas is used to make pure iron oxide from lean ores*; but, while this process may have possibilities in connection with the manufacture of iron by direct reduction (para. 75 below), it appears to be too expensive for the production of pure ores for use in blast-furnaces.

6. The process of sintering (para. 8 below) has tbe incidental effect of raising the iron content of the ore because the ore is heated to a sufficiently high temperature for water and carbon dioxide to be driven off. In the case of British ores, the iron content may be increased by as much as 50 per cent in this way. Thus the lack of an effective process for concentrating British ores has not been a serious matter.

Crushing and Screening

7. It was for long thought that the processes of crushing and screening were simple and that the problems were principally those of making the plant sufficiently robust to withstand the severe mechanical stresses. In screening, there was the additional problem that wet and sticky material was apt to " blind " (clog) the screens or sieves which separate the lumps from the fine particles of ore; but heating the screens by one means or another was an obvious remedy and some research was done on heating by electricity. It is now recognised that the processes of crushing and screening are more complex than was supposed; and B.I.S.R.A. is beginning more fundamental studies to supplement the industry's *ad hoc* work.

Agglomerating Fine Ores

8. There are various ways of agglomerating fine ore into lumps suitable for a blast-furnace burden. One of these is the process of sintering in which a mixture of fine ore with a small proportion of coke breeze and sometimes limestone is ignited on a travelling grate and the fine particles of ore are agglomerated by the heat of combustion. Shortly after the end of the war a number of British companies experimented with various forms of pellets or briquettes made by pressure or by extrusion and in some cases fired for additional strength. This work led to the conclusion that sintering was then still the best process for the treatment of both British ores and most of the imported ores used in this country; and further work was accordingly directed to improving the methods of sintering. Largely as a result of researches carried out in the

* L. Reeve, J. Iron and Steel Institute 1955, **181**, 26.

early nineteen-fifties by The United Steel Companies Limited in collaboration with B.I.S.R.A., British practice is highly efficient and is, indeed, unsurpassed for the treatment of lean ores. The methods of sintering developed in this country are now followed in many others. Further research is in progress; it is particularly needed on the quality of sinter, which varies greatly from one works to another.

9. For several reasons there has recently been a revival of interest in this country in pelletizing. One reason was the discovery that some iron ores and concentrates can be readily formed into round pellets or nodules in a simple rotary disc or drum and that by firing in a kiln or on a grate the pellets can be made strong enough to use in blast-furnaces. Another reason was the striking results obtained from some American blast-furnaces by using pellets for the burden. A further reason was that pelletizing plants are cheaper than sinter plants. But not all ores are suitable for pelletizing; and British steelmakers, who use a wide range of ores, still tend to prefer sintering because it is a more flexible process than pelletizing.

10. Research on the production of pellets is being energetically pursued in countries, such as Canada and Scandinavia, which have ample supplies of suitable ore. Research is also being done in those countries on the merits of using, as an enriched material for blast-furnaces, iron ore which has been partially reduced to iron in some form of kiln or shaft. Since the pelletizing of British ores does not look promising, it seems that, if pellets are required for use in this country, it may be better to import pellets made at or near the source of suitable foreign ores. It is thus desirable that the British industry should keep in touch with the work on pelletizing that is being done abroad and should study the effect on performance of using imported pellets in blast-furnaces.

11. The performance of a sintering machine can be greatly improved by pelletizing the material fed to it. This is because the operation of a sintering machine depends, in somewhat the same way as that of a blast-furnace (para. 2 above), on the even flow of gases through a bed of solids. It seems desirable that a measure of priority should be given to studies that are now being made of the benefits to be gained from this practice.

12. There has also been a revival of interest in this country in briquetting. This process has been out of favour because the early technique, which had been developed for the production of building bricks, was slow and expensive when used for briquetting iron ore. Briquetting techniques have recently been advanced and a consortium of several companies is now operating a pilot plant which should show whether briquetting is likely to be re-established as a method of agglomerating iron ore.

13. The present scale of work on agglomeration appears to be satisfactory in relation to the total volume of research in this country. The industry should, however, keep in touch with research overseas where conditions call for more intensive research on agglomeration than would be justifiable for the industry in this country. It seems probable that a wide range of processes will be needed abroad and that there will accordingly be opportunities for exports of plant from this country. British manufacturers of plant might therefore find it in their interest to intensify their own research on agglomeration.

14. In Britain the manufacture of coke is generally regarded as a separate industry. But since the iron and steel industry is a large consumer, and also makes most of the coke it uses, it necessarily takes a close interest in research aimed at improving the quality and reducing the cost of metallurgical coke. Research on coke is undertaken by the British Coke Research Association (para. 19 in chapter 3 above), by the National Coal Board and by a few steel companies. With the progressive depletion of British reserves of good coking coal it has become necessary to use an increasing proportion of inferior coking coals in blends for carbonisation. The quality of metallurgical coke has nevertheless been maintained through research on the blending of coal and on the use of additives such as coke breeze or flue dust. In addition, greater consistency in the quality of coke has been secured by the adoption of standardised methods of sampling, testing and analysis which have also resulted from extensive laboratory research. It is probable that, in the future, increasing proportions of poorly-caking coals will have to be used and that it will be necessary to investigate processes such as the manufacture of formed coke from such coals. A process of selective screening of coal, which has been developed in France and offers promise in some conditions is also being studied.

15. Other fuels are being substituted to an increasing extent for coke in ironmaking and the iron and steel industry is undertaking a considerable amount of research and development work in this connection. In these circumstances there seems to be no case for any large expansion of the research which the iron and steel industry undertakes on coke, although different considerations apply in the case of research undertaken by the coal and coke industries. The extent to which coke can hold its place in competition with other fuels for ironmaking will depend largely on whether the quality of coke can be maintained or even improved and on whether the price of coke can be kept competitive. It is, of course, primarily for the coal and coke industries to consider whether to expand the research they undertake with these objectives.

TRANSPORT AND HANDLING OF RAW MATERIALS

16. Half the cost of steel goes on raw materials and fuel and a considerable part of the prices of raw materials and fuel represents transport and handling charges. Research aiming at improving the efficiency of transport and handling is therefore of considerable importance. Problems of some complexity are involved. For example, an apparently simple way of reducing transport costs is to increase the size of the vehicle; and in the case of ships the economies of size increase with the length of the voyage. On the other hand, increasing the size of a ship makes its operation less flexible because it reduces the number of ports at which the ship can be accommodated. Transport and handling thus present a fruitful field for operational research and B.I.S.R.A. has done a great deal of operational research on the shipping and handling of imported ore.

17. The British productivity team on iron and steel which visited the U.S.A. in 1951 pointed out that American works had the benefit of better dock facilities than were available in this country, most American works having a deep-water dock alongside, and that arrangements for the transport of raw materials by rail were also more efficient in America than here. Many of the new works in Europe and in Japan also have alongside deep-water docks which they operate

themselves. As a result of the recommendations of the Rochdale Committee on port facilities* and of the proposals put forward in the report of the British Railways Board on "The Re-shaping of British Railways"†, there are now good prospects that the arrangements in this country will be improved. These improvements are urgently needed by the iron and steel industry; and research on efficiency in the transport and handling of raw materials will continue to be a matter of first importance.

IRONMAKING

18. Since the war a large amount of research on blast-furnace practice has been carried out in this country and as a result there has been a great improvement in the efficiency of blast-furnaces. The average consumption of fuel for each ton of iron made is now only two-thirds of what it was in 1945 and the average rate of output of furnaces is about 2½ times larger than in 1945. To a considerable extent the increase in the rate of output of furnaces is due to an increase in their average size; even so, furnaces of a given size now produce much more than they would have done in 1945.

19. The improvement in the efficiency of blast-furnaces has been world-wide and, in consequence, the blast-furnace has retained its dominant position in competition with other more recent processes for making iron.

20. A large part of the research into blast-furnace practice has been concerned with the preparation of the burden (paras. 2 to 13 above). In addition, the ironmaking division of B.I.S.R.A. has devised a convenient method (known as SCICE‡) of investigating the chemistry of the blast-furnace by passing gas of a controlled composition and temperature through a vessel containing material which can simulate a variety of burdens. By this means many studies can be made which would otherwise require an experimental furnace. Studies are also being made, both in this country and abroad, of methods of improving the efficiency of blast-furnace stoves in order to obtain the higher blast-temperatures required in modern practice. Some years ago the industry considered the possibility of providing hot blast to blast-furnaces by using a gas turbine instead of the conventional blower in conjunction with hot-blast stoves. Since this promised considerable economies in capital costs, the industry was prepared to meet the cost of building a pilot plant for large-scale trials; but further preliminary calculations and consideration of the practical experience of plant manufacturers suggested that it would not be possible to reach the high blast-temperature needed and the project was dropped. A gas turbine operating on blast-furnace gas, which was installed by Shelton Iron & Steel Limited in 1958 for simple coupling to a generator, has provided useful data on the problems of operating gas turbines on blast-furnace gas.

21. The United Kingdom industry is well to the front in the aspects of blast-furnace research referred to in the preceding paragraph. In research on the injection of fuel through the tuyeres in order to save coke, the lead was taken in countries where the prices of coke and of alternative fuels were such as to favour the use of alternative fuels to a greater extent than in this country. The

* Report of the Committee of Inquiry into the Major Ports of Great Britain. Cmnd. 1824—September, 1962.

† H.M. Stationery Office, 1963.

‡ Stationary Charge in Controlled Environment.

injection of natural gas is commonplace in the U.S.A. and in Russia; the injection of oil has been practised for some time in France. But progress has also been made in this country. Several British companies have now developed their own methods of injecting oil, and Stanton and Staveley, Limited are experimenting in collaboration with the National Coal Board on the injection of powdered coal. In addition, the injection of oxygen, which is complementary to the injection of fuel, is now practised by The Steel Company of Wales Limited.

22. In the U.S.A. and in Russia there has been for many years a practice of increasing the operating pressure by raising the pressure of the blast and at the same time restricting the outflow of gas at the top of the furnace. The advantage of this practice is that a greater weight of air can be blown with no increase in velocity and therefore without any greater disturbance of the burden or loss of material as flue dust. The difficulties of the practice lie mainly in maintaining gas-tightness at the furnace bell and the bleeder valves. Moderately high top-pressures are now used in several British furnaces.

23. In research on fuel injection and high top-pressure Britain has followed rather than led. The high level of efficiency resulting from efficient preparation of the burden and the availability of good coke have made it unnecessary for Britain to pioneer in these fields.

24. Blast-furnace research overseas is similar to that undertaken in this country and information is frequently exchanged. Some countries have built small-scale blast-furnaces for experimental work, the best known being two furnaces at Pittsburgh (paras. 28 and 30 in chapter 5 above) and a low-shaft furnace near Liège (para. 36 in chapter 5). In this country, B.I.S.R.A.*, in conjunction with Shelton Iron & Steel Limited, operated a 3-ft. experimental furnace at Shelton from 1943 to 1946. This experiment produced some useful knowledge of conditions inside a blast-furnace but it suffered from being ahead of its time. The problems of operating a small furnace were not then sufficiently understood, and observing and recording instruments were less advanced than they are to-day. The question whether the United Kingdom industry should set up another experimental furnace was discussed at length in 1961 by the Board's Technical Advisory Panel. The consensus of opinion was that the probable value of the results was not sufficient to justify the high cost of an adequate installation and that it should be possible to obtain equivalent information from a combination of laboratory work (using methods such as SCICE—para. 20 above) and trials in commercial furnaces.

25. As a result of research, British practice in ironmaking is at present well to the fore; but other countries which have the advantage of supplies of high-grade ore and cheap fuel are improving their practice so rapidly that Britain is in danger of losing her leading position. Some expansion of research may therefore be necessary. Automation in ironmaking and new ironmaking processes are discussed in later sections of this chapter (paras. 71 to 73 and 75 to 78 below).

26. In many countries such as Norway where electricity is cheaper to use than coke, the electric-smelting furnace is an established process for making iron. Such furnaces are also sometimes used as finishing units following direct

* Prior to 1944, BISRA's predecessor, the Iron and Steel Industrial Research Council.

reduction. In the United Kingdom there is at present little prospect of electricity becoming cheap enough to be a commercially attractive alternative to coke as a fuel for ironmaking. There is therefore no case at present for any substantial investment in research on electric smelting. This conclusion should, however, be reviewed from time to time.

STEELMAKING: OPEN-HEARTH AND CONVERTER PROCESSES

27. For the last hundred years the open-hearth furnace and the Bessemer converter have been the principal means of making steel. Both can be used for either basic or acid steelmaking; on the Continent the basic Bessemer process is more usually known as the Thomas process. Because of its flexibility (see para. 44 below), the open-hearth became the preponderant process in Britain, America and Russia. Steelmakers in Western Europe also employed open-hearth furnaces for making higher grades of steel from scrap and high-grade pig-iron, but relied mainly on the Thomas process for making common steels from molten iron. The Thomas process is a cheap way of converting iron into steel, but it can take only a small proportion of scrap and cannot be used with low-phosphorus iron. Thomas steel has a high nitrogen-content and this restricts the range of products for which it can be used.

Research in Britain and the U.S.A.

28. After the war research on steelmaking was mainly directed in both Britain and the U.S.A. to improving the open-hearth process. The Americans applied their skill in large-scale engineering to build larger furnaces and to equip them for rapid charging, for high rates of heat-input and for rapid handling of the product. In this country B.I.S.R.A. and a few companies, notably The United Steel Companies Limited, used model furnaces to elucidate the basic factors governing the transfer of heat and the flow of gases. These researches led to great improvements in the design of furnaces and in the performance of existing as well as of new furnaces. To cope with the improvement in the performance of furnaces better refractory linings were needed; valuable work on refractory materials has been done by the iron and steel industry, by the makers of refractories and by their respective research associations.

29. Progress has also been made in Britain and the U.S.A. in applying oxygen to open-hearth furnaces. This may be done in two main ways. One way is to use oxygen to accelerate the combustion of the fuel, and so increase the transfer of heat and the rate at which the furnace operates. The other way is to apply jets of oxygen to the molten metal and slag in the bath, and so accelerate the chemistry of the process, which is essentially a process of oxidation. Many years of research have been required to arrive at the best way of using oxygen in open-hearth furnaces. The introduction of oxygen through tubes (whether water-cooled or not) involved many problems in attaching additional moveable pipework to the furnace. Moreover, using oxygen to assist combustion raises the flame temperature, and applying oxygen-jets directly to the metal splashes more of it from the bath: in consequence the lining of the furnace deteriorates more rapidly and the life of the furnace is reduced. These problems were overcome in Britain by painstaking research on refractory materials for furnace linings and on aerodynamic design. In America steelmakers were ready to accept a reduction in the life of the furnace for the sake of increased output. The use of oxygen also led to the production of dense brown fumes of iron oxide

which caused public complaint. These fumes can be removed from the waste gases by installing gas-cleaning equipment, but this is expensive.

30. In Britain the two main landmarks in these advances were:—

(1) The development by The Steel Company of Wales Limited of a technique for introducing oxygen through the roof of a furnace. The oxygen pipes do not then obstruct charging and tapping operations.

(2) The design and erection of the " Ajax " type of furnace by the Appleby-Frodingham Steel Company branch of The United Steel Companies Limited in 1958. This permitted the use of oxygen on a more intensive scale than hitherto and resulted in much higher rates of output.

31. The intensive use of oxygen in open-hearth furnaces is not, of course, confined to Britain and the U.S.A. It is also noteworthy in Canada, the U.S.S.R., Italy and Japan.

32. Another method of increasing the output of open-hearth furnaces is to remove some of the silicon, and even of the carbon, from the blast-furnace metal before it is charged to the open-hearth furnace. Duplexing, i.e. the partial pre-refining of iron in a converter, has been known for many years but is expensive. The use of an " active mixer " to store the iron is more economic but removes less silicon. Much research has been done by the industry on methods of removing silicon in a simple vessel, or even in the transfer ladle, with the object of securing some of the advantages of duplexing by less expensive means. One or more methods of pre-refining are now in use at several works. B.I.S.R.A. has latterly devised a more highly developed process in which jets of oxygen break up the molten iron into drops and rapidly remove the silicon. Although these methods have improved the output of open-hearth furnaces, it is arguable that the direct application of oxygen, either in an open-hearth furnace or in a converter, is still to be preferred.

33. Although only a relatively small quantity of steel is made in Britain by the Bessemer process, some research has been undertaken on this process. In the late nineteen-forties Richard Thomas & Baldwins Limited developed methods of temperature control to minimise the effects of nitrogen, and Stewarts and Lloyds, Limited worked out a process for improving basic Bessemer steel in which, by the addition of mill-scale, oxidation was assisted and the nitrogen-content was reduced. During 1948 and 1949 a committee of B.I.S.R.A. made a special study of Bessemer steelmaking and issued a report on its prospects and possibilities. However, the advent of the new oxygen-converter processes (paras. 38–41 below) made further work inappropriate.

34. A process initiated abroad for producing steel of low nitrogen-content from a bottom-blown converter (para. 37 below) has been taken up and developed by The Steel Company of Wales Limited. The company now make an appreciable proportion of their steel by this VLN (very low nitrogen) process.

35. Steelfounders have for many years made steel from cupola-melted metal by top-blowing with air in the well-known Tropenas converter. In 1947 a British steelfounding company, Catton and Company Limited of Leeds, successfully used air enriched with oxygen in a Tropenas converter. This, in a sense, anticipated the LD process (para. 38 below). It was probably the first occasion on which oxygen was used in top-blowing to produce steel on a

commercial scale. The possibility of applying the process to the production of steel for other than foundry purposes was not however pursued; it was thought unsuitable for much the same reasons as applied in the case of the LD process (para. 44 below).

Research in Western Europe

36. In Western Europe at the end of the war, research in steelmaking was directed mainly to converter processes. In France the Institut de Recherches de la Sidérurgie (I.R.S.I.D.) and in the Benelux countries the Centre National de Recherches Métallurgiques (C.N.R.M.) both developed instruments which improved the control of the end-point of the blow; and I.R.S.I.D. also devised improved methods for measuring and recording the volume of the blast.

37. The main problem for steelmakers in Western Europe was, however, to develop a converter process that would produce steel not containing a high proportion of nitrogen. Research was therefore directed to the use of oxygen instead of air for the blast. It was found impracticable to use pure oxygen in Bessemer converters because the intense heat, generated where the oxygen blast met the metal, rapidly destroyed the bottom of the converter and the blast nozzles. As long as the usual bottom-blown vessel was used it was necessary to dilute the oxygen with a gas not containing nitrogen. Both steam and carbon dioxide were successfully used for this purpose in Belgium and in France.

38. At the same time investigations were made into the application of an oxygen jet to the metal from above, since this would greatly simplify the design of the vessel and the arrangements for blowing. In 1948 R. Durrer successfully operated a 3-ton top-blown converter in the steelworks at Gerlafingen in Switzerland. The first major advance took place, however, in Austria. After successful experiments in 1949 with the top-blowing of oxygen in a 2-ton experimental vessel at the Linz steelworks, the scale was increased to 15 tons and then to 30 tons. The process was known as the Linzer-Dusenverfahren (Linz jet) or LD process; as it was subsequently taken up by the other major Austrian steelworks at Donawitz, the initials LD are now usually taken to mean Linz-Donawitz.

39. The LD process could only be used with low-phosphorus iron. For Austrian steelmakers this was not a disadvantage; but steelmakers in other countries in Western Europe needed a process that could take high-phosphorus iron. After many unsuccessful attempts to adapt the LD process by adding lime in lump form, the problem was solved independently in Luxembourg and in France by adding powdered lime to the oxygen jet. The process was known in France as the OLP (oxygène lance poudre) and in Luxembourg and Belgium as the LDAC process, the letters AC denoting the firm (A.R.B.E.D.) and the research institution (C.N.R.M.) where the work was done.

40. There was also a need in Sweden for a process that would replace the bottom-blown converter and would produce high-grade steel from phosphoric iron. In 1948, at about the same time as the LD and LDAC processes were being developed elsewhere, Professor Bo Kalling experimented at the Domnarvets Jernverk with an inclined rotating vessel, somewhat similar to a cement mixer, and surface-blowing of oxygen. A 30-ton production unit was put into operation at Domnarvet in May, 1956. This process is known as the Kaldo process from the initial letters of Kalling and Domnarvet.

41. A process for making high-grade steel from phosphoric iron in a rotating horizontal vessel was developed by R. Graef at the Oberhausen steelworks in Germany in 1956. This is now known as the Rotor process.

Why the British and the Western-European Approaches Differed

42. The oxygen-converter processes have dominated technical progress in steelmaking since the war and, indeed, represent a completely new method of making steel. All these processes are now in use or about to come into use in this country, but they were developed almost entirely on the Continent. It has consequently been suggested from time to time that British research in steelmaking since the war has been wrongly directed and that British steelmakers have been reluctant to develop new processes. These are serious allegations and it is important to consider whether they are well founded.

43. The increase in the demand for steel after the war came largely in the form of flat-rolled and other products for which Thomas steel was not suitable because of its high nitrogen-content. A large proportion of the steelmaking capacity in Western Europe thus became obsolescent. It would have been very expensive for steelmakers in Western Europe to substitute new open-hearth for their existing Thomas capacity; and, in any case, the supplies of scrap available to them were not sufficient to support such a substitution on a large scale. They were, therefore, under strong commercial pressure to develop a converter process that would produce steel of low nitrogen-content. Moreover, in Austria, where the first oxygen-converter process (the LD process) originated, the available ores were unsuitable for the Thomas process.

44. In Britain, on the other hand, the existing open-hearth capacity was well adapted to meet expected demands. Open-hearth furnaces in this country were larger and more efficient than those on the Continent. A wide range of qualities of steel could be produced and widely varying proportions of scrap and pig-iron could be used. Many British Standard Specifications did not at that time permit the use of converter steel. Most British ores were unsuitable for the LD process and many difficulties were encountered in the earlier stages of the work that led to the LDAC process. Moreover, British steelmakers had reason to doubt whether they would be able to obtain the requisite large supplies of oxygen at prices low enough to make oxygen-converters economic in this country. In these circumstances it was reasonable to conclude that British research in steelmaking ought to be directed mainly to the further improvement of the open-hearth process. American steelmakers, whose circumstauces were similar in many respects, took the same course.

45. There is no evidence that the British industry has in fact suffered any serious disadvantage by not engaging in the development of oxygen-converter processes from the outset. British steelmakers have been able to acquire rights to use these processes on terms that are not unreasonable; whether they would have saved money by themselves developing similar processes can only be a matter for conjecture. The use of oxygen-converter processes in Britain is now extending rapidly; and, for the future, it would be unwise for the industry to depend mainly on further research carried out in the countries where these processes were first developed. A considerable amount of research on the basic physics and chemistry of these processes is now being done overseas; similar research should be undertaken in this country.

46. In electric steelmaking, British research has made a satisfactory showing. B.I.S.R.A. developed a system now well known, for controlling the input of power automatically; it economises electricity and reduces wear on refractory linings. It is being adopted in the new electric-melting shop at the Steel Peech & Tozer branch of The United Steel Companies Limited. This shop will be the largest of its kind in the world and will also incorporate other advanced features such as centralised control of the furnaces. The G.K.N. Steel Company Limited have developed at their Brymbo Steel Works a pre-refining technique that permits a high proportion of molten blast-furnace iron to be used in the charge for electric furnaces. Much of the research on electric-arc furnaces lies in the field of electrical engineering. In Sweden, electrical engineers have developed, in conjunction with a Swedish steelmaker, a means of stirring the bath of liquid steel by passing a low-frequency alternating current through a coil below the furnace. This development has been adopted at several electric-arc furnaces, including some in Britain. A good deal of research on other forms of electric furnace has also been done both in this country and abroad; several British companies have installed consumable-electrode vacuum furnaces of American or Continental design. Furnaces of this type are used when steels of the highest quality are required and cost is a secondary consideration.

USES FOR SLAG

47. The industry has always been interested in research aimed at profitable outlets for the slag produced in the course of manufacturing iron and steel. Many of the products that can be made from slag are, however, subject to competition from cheap natural materials. Thus, although slag is produced in large quantities, the profits (if any) to be obtained from processing it for disposal are small. This may in turn limit the amount of research that can be justified. Both in Britain and in Germany much research has been done on the factors governing the suitability of blast-furnace slag as a material for building, for road-making and for railway ballast. B.I.S.R.A. has recently found that blast-furnace slag can be converted into a ceramic substance with valuable structural and decorative properties; the Association is endeavouring to develop an economic manufacturing process. Phosphoric steelworks-slag is a well known fertiliser and research to improve its agricultural properties is being pursued.

48. The industry have also considered from time to time the possibility of making use of the large amount of waste heat that remains in the slag at the end of the ironmaking or steelmaking process. The difficultics are, however, very great and the prospects of a successful outcome of any research are slender. There appears to be little case for giving high priority to a major research effort on this problem.

THE CASTING OF STEEL

49. In the classical method of steelmaking, the molten steel is poured into moulds to form ingots. The ingots are kept hot in "soaking pits" (or are re-heated) until they are at the right temperature throughout, and are then rolled into semi-finished products such as billets, blooms or slabs. These are converted into finished products by further rolling and other processes.

50. The casting of ingots was an early subject of co-operative research in this country. It was taken up by the " Heterogeneity in Steel Ingots Committee " which The Iron and Steel Institute set up in 1924 and has since been pursued continuously. The work initiated in Britain has also been followed up in other countries. Yields of finished steel and the life of ingot moulds have been improved, and the causes of many common defects in ingots have been elucidated. Since the war there have been two important new developments, namely, continuous casting and vacuum casting.

Continuous Casting

51. For many years the possibility has been studied of making finished products by a continuous process of pouring steel from a ladle through a mould. With such a process, one piece of plant would replace the equipment for casting ingots, the soaking pits and the rolling mills, with the result that both capital and operating costs would be reduced. Moreover, the proportion of the steel that has to be discarded because it is unsound would be lower, and yields would thus be further improved.

52. The continuous casting of finished products has yet to come but the continuous casting of semi-finished products is now established. The principle is extremely simple. Liquid steel is poured into a water-cooled mould of the shape required. The steel next to the walls of the mould solidifies and the casting is withdrawn from the bottom of the mould at the same rate as the steel is poured in. The emerging casting is then sprayed with water and soon solidifies completely. This method has been used for many years in casting non-ferrous metals; but steel solidifies at a much higher temperature than the common non-ferrous metals and is therefore more difficult to keep liquid for pouring. Further difficult problems arise in avoiding splashing, in synchronising the rates of input and withdrawal and, above all, in ensuring that the skin of the casting, which is inevitably thin and weak when it leaves the mould, does not tear. These factors limit the speed of casting. When castings of small cross-section are required, several strands must be used simultaneously if reasonable quantities of steel are to be handled in the time available; this adds to the problems of synchronisation.

53. Research on continuous casting was started by B.I.S.R.A. in 1947 and independently by a British maker of special steels at about the same time. The available resources were, however, limited; and it appeared for a time that steelmakers in Russia and in Western Europe were making rapid progress and were planning a number of large installations for production. The British research effort was increased sharply in 1951 as a result of an urgent need which arose at the Barrow Steel Works then managed by The United Steel Companies Limited for the Iron and Steel Corporation of Great Britain. The billet mill at these works was approaching the end of its life and some form of continuous casting offered the most economic way of providing the billets which the mill had up till then supplied. The billets required were of small cross-section down to 2" square; it is especially difficult to cast such small billets continuously at speeds fast enough to empty a ladle before the steel becomes too cool. A pilot plant for experimental work was commissioned at the end of 1952 and, although formidable difficulties were encountered, the company were able by 1958 to decide to adopt continuous casting for the whole of the steel produced at their Barrow Steel Works.

54. Meanwhile, B.I.S.R.A. had proceeded with its general research, using experimental plant in its laboratories in London and Sheffield, and had obtained a great deal of fundamental information on the physics and metallurgy of the process, for example on the transfer of heat from metal to mould and on the factors affecting the rupture of the skin of the casting. The Association had also produced, for companies interested in the process, experimental castings in a large number of sizes from many types of steel. Co-operative research was also carried out from 1954 to 1957 on a pilot plant installed at a Sheffield works and financed by a consortium of twelve manufacturers of alloy steel.

55. Between 1958 and 1960 B.I.S.R.A. and the Benelux Centre National de Recherches Métallurgiques collaborated in research at a Belgian steelworks on the continuous casting of rimming steel. Work has subsequently been done on this problem by The Steel Company of Wales Limited in collaboratiou with B.I.S.R.A. and the designers of the large continuous-casting plant at the company's Abbey Works.

56. A British company specialising in the construction of continuous-casting plants recently developed, in collaboration with B.I.S.R.A., a method of casting small billets in multiple moulds; this should simplify the problems involved in casting large quantities of steel into billets of small cross-section.

57. During the last few years rapid progress in continuous casting has also been made in Western Europe and in Russia, and a number of commercial installations are now in use. British research, after a slow start, has proved adequate to meet the needs of the industry in this country and has also led to orders for British plant from several overseas steelworks. Since, however, further rapid developments in continuous casting are to be expected, it is desirable that British research in this field should be expanded.

Vacuum Casting

58. The record of British research on vacuum casting is less satisfactory than on continuous casting. Vacuum casting has been developed for some steels of high quality because gases of various kinds are released when steel cools. Many of these gases do little harm because they either escape during casting or form internal bubbles that disappear in the course of rolling or forging. Hydrogen, however, causes problems; in large ingots for forging, it may remain in the steel long enough to cause fine cracks which are dangerous weaknesses. The normal practice in the past has been to heat the steel for long periods so that the hydrogen can diffuse out before it gives rise to such defects. It was always evident that, if a vacuum could be applied during casting, most of the hydrogen would escape before the steel solidified and that the defects to which it gives rise would be eliminated or at least reduced. The possibility of research on these lines was discussed shortly after B.I.S.R.A. was established. In studying this problem experiments on a reduced scale would be of no value and the industry considered that the cost of the equipment needed to experiment with large ingots would be prohibitive. Some steelmakers abroad were not thus deterred and commercial installations for vacuum casting have been developed both in Germany and in the U.S.A. Similar plant is now being installed at several British steelworks; more economical installations may result from work now being done by B.I.S.R.A. on alternative methods of degassing steel both by applying a vacuum and by using jets of inert gas. But, until recently, British

users who required forgings made from vacuum-degassed steel had to obtain them from abroad.

59. It has now been found that vacuum casting can assist the de-oxidation of common steels. The advantages of such a practice are being increasingly recognised and it may be expected to extend. For this reason also research on vacuum casting will continue to be important.

ROLLING AND FORGING

60. Although continuous casting is advancing rapidly, rolling-mills and forging hammers or presses will remain for many years the principal means of shaping finished steel; research on these processes thus remains highly important. Many of the advances in rolling-mill engineering have come from the U.S.A. In Britain new rolling-mills are required only in small numbers; this has limited the scope for research aimed at major changes in design. The position is different in the U.S.A. with its very much larger output of steel and consequently larger market for mill equipment. Moreover, American technology has always been strong in heavy mechanical engineering.

61. American developments of rolling-mills have evolved in the form of improvements of well tried designs. British manufacturers of rolling-mills have kept closely in touch with these developments and, through agreements with American manufacturers, have maintained their ability to supply up-to-date equipment.

62. In Britain, research into rolling-mill engineering has been undertaken by plant manufacturers, by steel companies and by B.I.S.R.A. The plant manufacturers have directed their attention to improving their own designs; in some cases the improvements amount to substantial departures from previous practice. During the last ten years, plant manufacturers have recruited increasing numbers of graduates to their staffs and an extensive collaboration has developed between the manufacturers and B.I.S.R.A. The Association has tended to concentrate on the fundamental aspects of the design and operation of rolling-mills and has evolved some new principles. One of the first fruits of experimental work at the Association's rolling-mill laboratory in Sheffield was a system by which the gauge (i.e. thickness) of strip is automatically regulated and a more uniform gauge obtained. This system is now in use both here and abroad and the Association is receiving royalties from several foreign licensees. The Association has also developed a new type of stand for rolling-mills. It is of opposed cantilever design; each of the pair of rolls is carried in bearings at one end only and the bearings are disposed on opposite sides of the rolling line. A stand of this type has been shown to be suitable for rolling bars or rods. It has the substantial advantages that rolls can be changed very quickly and can be pre-set so accurately as to make test runs unnecessary. A trial installation has been run at a rod mill, and a three-stand mill of this type is in experimental use at the Association's laboratories in Sheffield. British manufacturers have taken licences to build mills on this principle.

63. In the course of their work on forging, B.I.S.R.A. has developed an automatic system of position-control which gives great accuracy and speed of

operation. This is a major invention and is already in use in some forging presses of medium and smaller sizes. The Association has also studied the flow of material under deformation by using a simple experimental technique in which models composed of layers of plasticine in different colours readily exhibit the phenomena involved. The cold-forming of steel either by extrusion or forging is developing steadily and has by no means reached its limit. This is more a matter of engineering than of steelmaking technique; but steelmakers have still to provide the steels that are required both for processing and for tools. Research both here and on the Continent is directed towards the development of steels that are more suitable for cold-forming and of tool steels that will resist a surface pressure of more than 125 tons a square inch.

ANNEALING, COATING AND FINISHING

64. For the same reasons as in the case of rolling-mill design (para. 60 above), many of the major developments in tinning and galvanising have originated in the U.S.A., the first plants for electrolytic tinning, for continuous annealing and for open-coil annealing having been developed there. Some British firms have, however, developed their own versions of some of these processes which they claim are simpler and more economical; more of this kind of research should be done. B.I.S.R.A. has also made considerable advances in this field and has developed a new continuous-annealing system which is in operation as a pilot plant in South Wales. This system is of great promise; licences to use its principles have been taken up by plant mauufacturers. British steelmakers are helping with further developments. The Association has also developed new methods of coating steel with aluminium both by hot-dipping and by electrophoresis. In the latter process the strip is passed through a suspension of aluminium powder in a solution consisting mainly of either methylated spirit or methanol and, by the application of an electric potential, the powder is attracted to the strip and adheres to it. At this stage the aluminium coating will easily rub off, but it is sufficiently adherent to stay in place while the strip is rolled and heated; after this treatment the coating is as adherent as an electro-plated coating. The process is simpler and cheaper than electroplating and the coating stands deformation well. The process is being further developed for other metallic coatings of steel. The Association's original process for coating steel with plastic sheet (Plasteel) has been rather overshadowed by a process developed independently by one of the larger steelmakers. The Association has, however, developed a simple process for applying a powder to produce a cheaper form of plastic-coated sheet (Pacplate) which is adequate for many purposes; this process should have a valuable future. Although plastic-coated sheet has been on the market for some time, further research is necessary to reduce the cost of production and to extend the market.

65. British manufacturers of sheet and strip have developed processes of their own for various electrolytic and hot-dipped coatings; they also use processes of American origin. The British manufacturer referred to in the preceding paragraph has taken the lead in the production of a plastic-coated sheet that has been used effectively for products requiring a decorative finish, e.g. furniture. Research aimed at a one-coat process of enamelling, with corresponding economies in manufacturing costs, is proceeding both in this country and in America.

66. Much has been heard recently of the production in the U.S.A. of extra-thin tinplate, down to 45-lb. substance* and even less; two American manufacturers have produced experimental quantities of foil as light as 5-lb. substance. British mauufacturers of tinplate are keeping in close touch with these developments. The demand for thin tinplate in this country has hitherto been of slow growth, possibly because the competition of other materials has been less severe than in the U.S.A. It is important that British manufacturers should be in a position to meet any demand that may arise in this country for thin tinplate. This may, however, be a case in which it is better for British manufacturers to follow the development of American practice than to undertake parallel developmeut work; the resources that would be required for such work can probably be used to greater advantage in other ways.

67. Very thin tinplate and other fragile kinds of strip are liable to be damaged during manufacture by contact with the guide rolls. B.I.S.R.A. has invented an air-cushioned guide, or " hover-pulley ", which eliminates this coutact. (The principle is the same as that used in hovercraft.) This invention should also be useful when, even though the strip may not be particularly fragile, the quality of its surface is especially important.

68. In many works, the inspection of finished steel still consumes a great deal of time and labour. Research on mechanised or automated inspection is being done by B.I.S.R.A. and by several steelmakers. Progress has been made, but there is considerable difficulty in detecting small defects in large quantities of steel. This appears to be a profitable field for intensified research.

ALLOY AND SPECIAL STEELS

69. The British iron and steel industry undertakes extensive research on alloy and special steels; a complete account of it cannot be given in a general report. Makers of these steels were the first in the industry to undertake research on a substantial scale. The work of Hadfield on manganese steels and that of Brearley on stainless steel are well known classical examples. Steels with new properties are continually being announced—for example the boron steels for components of nuclear reactors, steels suitable for jet engines (licences for which have been taken by steelmakers overseas including some in the U.S.A.) and steels which, because they resist " creep " at high temperatures, are suitable for the boilers and machinery of power stations. An interesting and praiseworthy development in this field is the fundamental study of the physics of metals that has been made possible by the development of more advanced equipment for X-ray analysis and of electron microscopes. Previously, new alloys were usually developed by adding alloying elements on the basis of " try it and see ". More sophisticated methods are now being used: they depend either on studying the behaviour of intruding atoms in metal crystals, or on designing experiments statistically in such a way as to minimise the number of formulations that must be tried in order to establish the best composition.

* " Substance " is the weight in pounds of a standard area (approximately 218 sq. ft.) of tinplate, " common " substance being 108 lb. Substance has hitherto been used to specify the thickness of tinplate, being proportional to it. A revised nomenclature for tinplate, in which (*inter alia*) nominal thickness will be specified in inches, is being introduced in the United Kingdom with effect from the end of 1963.

Research in this field appears to have been adequate and, provided the present expanded studies of metallurgy continue, the prospects are satisfactory. Similar work is being pursued intensively abroad, particularly in America and Japan where research laboratories are liberally provided with the expensive apparatus needed for this kind of work.

CORROSION

70. Liability to corrosion is the most serious drawback to steel in many of its uses. Steel components have to be thicker than would be necessary if they were less liable to corrosion; protective measures are also costly. Research on corrosion has been in progress in this country for many years. The Iron and Steel Institute set up in 1928 a Corrosion Committee which issued its first report in 1931. The Committee maintained its own laboratory and testing stations. Its work was taken over and has been continued by B.I.S.R.A. The Association maintains an information bureau from which advice can be obtained on how to combat corrosion. Steel companies have also done valuable work, notably in developing steels which resist corrosion but are yet cheap enough to be used for general structural and engineering purposes. The record of British research on corrosion is good; but the importance of the subject is such that a greater research effort can be justified.

AUTOMATION

71. In the steel industry automation is being applied fairly extensively; in elementary forms, such as the pre-set control of rolling mills, it is becoming the general practice. Some of the earliest forms of automation were applied to open-hearth furnaces before the war, e.g. the automatic control of chimney dampers based on measurements of pressure inside the furnace. Automatic control of roof temperature, which reduces the flow of fuel when the furnace becomes too hot, was developed soon after the war, a crude installation having been tried even earlier. Installations in which several systems are linked have been developed more recently. Automatic control has been applied to the composition of the feed to sinter plants, to the sequence of operations in charging blast-furnaces and to rolling-mill schedules. To specialists in automation the examples just mentioned may seem elementary, but there are particular difficulties in applying automation to the production of steel. All systems of automatic control depend on the possibility of reliable measurements of the factors such as temperature, pressure and chemical composition on which the control is to be based. Such measurements are difficult to obtain in the type of plant used in the production of steel; temperatures are high, chemical conditions are severe, and the plant is often subject to shock and vibration.

72. The number of computers in use in British steelworks is growing rapidly. For example, The United Steel Companies Limited will shortly have six computers in use, including a unit for controlling the operation of the new electric furnaces now being installed at the company's Steel Peech & Tozer branch. Computer control of a billet shear is being used successfully by a manufacturer of alloy steel and, by ensuring the maximum yield of billets, is achieving notable economies. The plans for automation at the new Spencer Works of Richard Thomas & Baldwins Limited (which have been described in several trade journals) embody a great deal of research; the ultimate objective is extensive control of plant and information-handling systems through a multi-computer system.

The Steel Company of Wales Limited is applying a similar form of control to a cold mill.

73. To be worth while, automation must yield economic advantages. It seems unlikely that further large reductions in manpower will be possible in the primary processes of steelmaking because they are already highly mechanised. There is more scope for savings of manpower in finishing and inspection departments (c.f. para. 68 above). The general opinion is that the benefits of automation will mainly take the form of improvements in quality and yield; but knowledge of the potentialities and prospects of automation is still in its infancy. Although the industry has been alert in investigating applications of automation, the Board's Technical Advisory Panel has suggested that this field deserves more attention.

OPERATIONAL RESEARCH

74. The industry is well advanced in operational research. It began in an elementary form before the war when the Iron and Steel Industrial Research Council applied statistical methods to study the performance of blast-furnaces and open-hearth furnaces. When the war ended, the methods of operational research that had been developed for military purposes were rapidly applied to steelmaking. B.I.S.R.A. has taken a leading part in fostering operational research in the industry. The Association maintains a large Operational Research Department which has many valuable results to its credit, for example a determination of the best methods for handling ore. Much of the Department's work has been concerned with the particular problems of individual works and has led to improvements in operation. The Department also collaborates with the British Iron and Steel Federation on problems of safety in works. The principal steel companies are fully convinced of the value of operational research; they have their own departments which are employed over the full range of their operations and are especially useful when modifications or additions to plant are being considered. In several cases it has been found that an output thought to require additional plant could be obtained by relatively minor modifications to existing plant.

UNCONVENTIONAL PROCESSES

75. The foregoing discussion has been mainly concerned with conventional processes, which now include continuous casting. There are other ways of makiug iron and steel which have been considerably developed in some countries. In ironmaking, such processes include the low-shaft furnace and the many "direct reduction" processes. Their main objective is to use fuels that would be more economical than metallurgical coke and plant that would be simpler and cheaper than the blast-furnace. The principles of these processes are well known in Britain, but there is not as strong a case for development work in this country as in others that have cheap natural gas, cheap hydro-electric power, very pure ores producing little slag or some other natural advantage. It seems that, even if British research were intensified, there would still be no immediate prospect of iron and steel being made more cheaply in this country than by efficient conventional methods. B.I.S.R.A. carried out eight years of research on a process for the manufacture of steel by direct reduction; the Association has recently terminated this project because of the technical difficulties and because

of doubts as to whether the process would prove more economic than conventional processes. An alternative process that was being studied by the United States Steel Corporation has been put on one side for similar reasons.

76. Although the new steelmaking processes typified by the top-blowing of oxygen are likely to hold the field for some time, work is being done both in the U.S.A. and in Japan on the manufacture of some kinds of finished steel products directly from pure iron powder by rolling. This is a subject on which the British steel industry might well consider doing more work.

77. There has recently been a revival of interest in the possibility of converting iron into steel by a continuous process as the iron emerges from the blast-furnace (or other ore-reducing plant) and thus avoiding the need for a separate steel-melting shop. This is the ultimate objective of the work of B.I.S.R.A. on the spray-refining process referred to in para. 32 above and of other work being done by suppliers of oxygen. At least one University in this country proposes to set up a pilot plant for experimental work. Experiments have already been done at an Australian steelworks. The difficulty lies, at present, in conducting a refining reaction on a stream of liquid metal of which the composition and rate of flow are very unstable. Advances in blast-furnace practice should reduce the instability of conditions within the furnace; and advances in automation should lead to better means of adjusting the refining process to variations in the compositions of the furnace input and output. There is thus a prospect of ultimate success.

78. The continuous casting of steel dispenses with ingots, soaking pits and primary rolling-mills. The unconventional processes for steelmaking that have been referred to are attractive because they would similarly eliminate major portions of the equipment that conventional processes require. If, for example, it were possible to link the chloridising process for producing pure iron oxide (para. 5 above) with direct reduction (para. 75) to give a pure iron powder and to roll such a powder directly into strip (para. 76), the savings in costs of production should be enormous. The Board feel that more thought should be given to projects of this kind even though it may be many years before they can be realised.

79. The industry is now completing a large programme of modernisation and expansion, and the processes and plant installed under this programme will provide the bulk of the industry's production for several years to come. In these circumstances a substantial proportion of the industry's research effort will properly be applied to the further improvement of existing plant and processes. But whenever new or additional plant may be called for, the industry should be ready with designs and processes of the most up-to-date and economical kind, so as to secure the largest possible reductions in capital and operating costs of production. The Board therefore consider that the industry should devote more resources than hitherto to research that looks ten or more years ahead; and that such additional research should be principally directed to new processes radically different from those at present used and should have as one of its objects the ultimate replacement of batch production by continuous processes. The development of continuous processes will involve research directed to more advanced techniques in instrumentation, control, sampling and chemical analysis.

Chapter 7

Are the Research Arrangements of the British Iron and Steel Industry Adequate

1. Whether an industry is doing an adequate amount of research is a question to which there is no precise or entirely objective answer. A number of tests have been suggested. None of them is decisive; in combination they may provide the basis for a reasoned judgement.

2. Expenditure on research may be regarded as an investment in knowledge and as thus analogous to capital expenditure on, for example, new plant. In research there is no limit to the projects that might be undertaken with some prospect of commercial benefit. Similarly, the investments in new manufacturing plant that a company might make with some prospective profit will usually exceed the capital available. In both cases it is a question of choosing the projects that seem likely to be the most profitable. The analogy should not, however, be pressed too far. It is usually much more difficult to make reliable estimates of the return on an investment in research than on an investment in plant. Estimates of the cost of research are unreliable because the course of the work is inherently uncertain. The success of a research project cannot be guaranteed. The return may be very high, or it may be little or none; and the time it will take to realise is highly speculative. When research is directed to reducing the costs of an existing process or product, it is often difficult to forecast the savings accurately. The commercial value of the results of a successful research project may also be affected by unforeseen technical and commercial developments that occur elsewhere while the research is in progress. The longer a research project is likely to take, the more difficult it is to make a reliable estimate of the commercial return.

3. It has been suggested that the adequacy of an industry's research can be tested by the number of urgent problems awaiting solution. This test is hard to quantify. If however an industry seemed not to be applying sufficient resources to a number of research projects that appeared commercially worth while, it might be thought to indicate an inadequate programme of research.

4. Another test is to compare the research ratio of an industry (as defined in para. 12 in chapter 1 above) with the research ratios of other industries. As has already been pointed out (para. 13 in chapter 1), the validity of this test is very doubtful. There is no inherent reason why industries of different kinds should have similar research ratios. As a leading economist has put it:

> " Some authorities seem to establish a case for more extensive industrial research and development by pointing out that some industries spend less

than others on research and development and by assuming that all industries would gain by raising themselves to the standards of the highest. Now different industries vary greatly in almost every imaginable sense; in capital investment per head; in the raw materials consumed per unit of output; in the types of labour employed; in the methods of financing new expansion; in the extent to which they buy finished or semi-finished parts from other industries; and so on. Nobody doubts that these variations represent the proper responses of different industries to the different circumstances which face them. Why then should it be assumed that it is a golden rule, an inflexible uniformity, that every industry should spend the same proportion on research and development or devote the same proportion of its labour force to these ends?" *

Nevertheless if an industry's research ratio is lower than those of other industries whose circumstances appear to be similar, it is a point that cannot be ignored in considering whether the industry's research is adequate.

5. There is more to be said in principle for comparing the research ratios of industries of the same kind in different countries. In the case of iron and steel, however, the utility of this test is limited by a paucity of information as to the research expenditure of iron and steel industries in other countries. Differences between the circumstances of those industries and of the British iron and steel industry must also be allowed for.

The General Branch of the Industry

6. The fact that the industry is now using a number of production processes developed abroad is not necessarily an indication of a deficiency in research. It is not to be expected that any one country should be in a leading position in all branches of research in iron and steel; the resources available for research are nowhere unlimited. It may, on occasion, be better for an industry to acquire licences to use processes developed abroad rather than to engage in parallel development work itself; it is a matter for judgement on the merits of the case. It would, however, be unwise for an industry to rely on foreign developments to the total neglect of research in any main field. A company with no expertise of its own is likely to have difficulty in applying the results of research done by others and may find itself at a disadvantage in negotiating for the purchase of patent rights and "know-how". It is also to be remembered that the terms of a licence often restrict the freedom of the licensee to compete in foreign markets; and that, if the terms include the right to be informed of subsequent developments, the licensee will not receive this information until some time after the licensor has it.

7. Some users of steel have alleged that the industry has been unwilling to develop new materials for special purposes. The Board's Technical Advisory Panel considered that this allegation was not well founded, except possibly in the case of some highly specialised requirements (e.g. alloy steels for use at ultra-high temperatures) where the demand was much too small to provide an adequate return on the amount of research that would be required. The Panel thought that in such circumstances it would be reasonable for the user to bear

* Professor J. Jewkes, Professor of Economic Organisation at Oxford University, in an address to the meeting at York in September, 1959, of the British Association for the Advancement of Science.

part of the cost of the research or for the research to be undertaken jointly by the user and the supplier of the product. Nevertheless, the industry has on many occasions carried out research to meet the special requirements of the armed forces and other users, even though the commercial return was inadequate and the benefit to the industry was mainly in prestige.

8. It has also been suggested that the industry's record in productivity indicates an insufficiency of research. The productivity of the industry is lower than that of steelmakers in the U.S.A. and of some major Commonwealth producers of steel; and productivity has not been rising as fast in this country as on the Continent. The productivity of an industry depends on many factors besides research, for example on the size of plant units and on manning practices. The Board's Technical Advisory Panel considered that, while productivity would doubtless have benefited from more research, other factors had had a greater effect in the period since the end of the war. In particular, because demand had for several years tended to outrun capacity, it had been necessary for the industry to keep older and less efficient plant in production until new and modernised capacity was available; and, in some cases, closures of older plant had been deferred partly on account of social considerations.

9. The industry has also been criticised on the ground that its research effort is small in relation to its size. If British industries are arranged in the order of the research ratios estimated in the D.S.I.R. and F.B.I. enquiries referred to in chapter 1 (para. 12) above, the iron and steel industry stands in a low position. Some particulars of the research ratios estimated in the D.S.I.R. 1959 enquiry and in the F.B.I. enquiry are given in Appendix II. (Owing to differences in the method of compilation, the research ratios estimated in the D.S.I.R. 1955 enquiry are not comparable with those estimated in the D.S.I.R. 1959 enquiry). It should be noted that the research ratios estimated in the F.B.I. enquiry (and those estimated in the D.S.I.R. 1955 enquiry) do not take account of research carried out by co-operative research associations; in the iron and steel industry the expenditure of the research associations accounts for a relatively high proportion of the industry's total expenditure on research. In another respect also, the research ratios referred to do not provide a fair comparison where the iron and steel industry is concerned. The sum total of the knowledge that an industry gains by applying a given amount of resources to research depends in part on the extent to which manufacturers in the industry exchange scientific information and the extent to which they duplicate research projects. Duplication of research projects is not always or entirely wasteful. Competition in research may lead to an earlier solution of the problem, and unexpected but valuable information may be obtained in the course of repeating an investigation by a different method. But when rival teams work in competitive isolation, the duplication of work is apt to be extravagant in resources. There is no doubt that in some industries duplication of projects increases the total expenditure on research without a commensurate addition to the knowledge obtained. The exchange of scientific information is probably as extensive in the iron and steel industry as in any other British industry and there is very little wasteful duplication of work. Companies in the iron and steel industry tend to acquire licences to use new processes or products developed by others, rather than to engage scientific resources in developing their own alternatives. The main point to be remembered, however, when research ratios are being considered is (as has already been mentioned in para. 4 above) that there is no inherent reason

why industries should be alike in their research when they differ widely in other respects. Thus the fact that the enquiries referred to showed the iron and steel industry as having a relatively low research ratio should not be regarded as conclusive evidence of an inadequate research effort, although it may indicate a need for further investigation.

10. It should also be remembered in connection with the industry's record in research that, for some ten years after the war the industry's most urgent need was to modernise and expand its production capacity as rapidly as possible. This made heavy demands on the managerial and technical resources of the industry; and these demands had to be satisfied before research could be expanded*. Nevertheless, the industry has solid and valuable achievements to its credit in research since the war. Opinions may differ as to the adequacy of the industry's research during this period; but it is more profitable to consider whether its present arrangements are adequate to meet the needs of the future, particularly in view of the radical change in its circumstances that has taken place during the last few years. For many years after the war the industry had no difficulty in selling all it could produce and was indeed making every effort to increase its capacity. It now has ample capacity and is also subject to growing competition from rival steelworks abroad. Whereas Britain was at one time a low-cost producer of steel, many of the industry's foreign competitors now have advantages in connection with raw materials or fuel or transport facilities or in more than one of these respects. Steel is, moreover, subject to growing competition from rival materials such as plastics, aluminium and concrete. In this situation, it is the competitive position of the industry that matters. It is obviously important to find new uses for steel, to meet the competition of other materials in existing uses of steel, and to improve the competitive position of exporters of steel and of goods made from steel. Special attention should therefore be paid, in all the industry's research, to developments that promise to reduce costs of production and, in particular, the cost of capital equipment for each unit of output.

11. It has already been suggested that, in a number of important fields, an increase in the resources the industry applies to research would be beneficial. The fields referred to include ironmaking, oxygen steelmaking, continuous casting, mechanised or automated inspection, corrosion, automation in the production of iron and steel and work looking ten or more years ahead and principally directed to the development of processes radically different from those at present in use (paras. 25, 45, 57, 68, 70, 73 and 79 in chapter 6 above). The Board's Technical Advisory Panel have recommended that the industry's research effort should also be increased in other directions; these recommendations are dealt with in the next following paras. 12 and 13.

12. Some critics, while not alleging that research in iron and steel has been inadequate, have suggested that the industry has been slow in applying the results. It has often been said that more large-scale work should be done on pilot or production plant so as to accelerate the application of the results of research. The Technical Advisory Panel accordingly considered whether an increase in large-scale experimental work was called for. The Panel noted that

* There is evidence that the companies that completed their programmes of modernisation and expansion soonest were among the first to expand their research; and that companies whose programmes of modernisation and expansion were on a larger scale, and therefore took longer, were later in expanding their research.

a number of companies in the industry already did a great deal of work not only on pilot plants but also on full-scale plant in the course of production. Such work is expensive for the companies concerned; and it was suggested to the Panel that large-scale experimental work that was of value to the industry generally should have financial aid from central funds even though it were carried out hy a company. On the other hand, it was thought that it would be a pity to do anything that would make companies less willing to undertake large-scale experimental work at their own cost. The Panel recommended that the provision of resources for large-scale experiments on either pilot or production plants should be maintained and extended, but expressed no view as to how such work should be financed. The Board agree that an increase is required in the resources applied to large-scale experiments. The income of the central research association is not at present large enough to support extensive work on pilot plants. The Board consider that special arrangements for financing work on pilot plants should be made more frequently than hitherto; the Board have in mind the arrangements under which a number of companies shared the cost of some research on continuous casting from 1954 to 1957 (para. 54 in chapter 6 above) and the arrangement that was contemplated in connection with research on gas-turbine blowing for blast-furnaces (para. 20 in chapter 6). The Board suggest that the British Iron and Steel Federation should organise similar arrangements in appropriate cases.

13. Because market development is now of great and growing importance (para. 10 above), the Technical Advisory Panel recommended that the industry's technical research in aid of market development should he extended.

14. In the circumstances that have been described it seems clear to the Board that a suhstantial increase in the research effort of the industry is now called for. The extent to which companies should increase their individual research efforts, and the extent to which additional resources should he provided for co-operative research through research associations or otherwise, are questions for companies individually, and for the industry collectively, rather than for the Board to decide. The Board, however, feel bound to attempt to quantify, if only provisionally, the increase that now seems desirahle in the total research effort of the industry.

15. Some guidance as to the size of this increase may he obtained hy considering what would be a reasonahle provision for research in a representative steelworks making from, say, 1 to 1½ million ingot tons of heavy steel products a year with a total value of hetween £30 million and £50 million. Such a works may be assumed to have some six production departments concerned with coke, the preparation of ore, blast-furnaces, steelworks, rolling and finishing, and some ten service departments for fuel, refractories, chemistry, physics, metallurgy and quality control, civil engineering, mechanical engineering, electrical engineering, instruments and automation, and operational research. The research department serving the works would require at least one team, consisting of, say, two qualified scientists or technologists and two assistants, for research associated with each of the sixteen other departments. The minimum provision for staff directly engaged in research would thus amount to about 64, of whom 32 would be qualified scientists or technologists. When allowance is made for metallographic, workshop, library and other services, the total staff required for research would be between 120 and 130, of whom about 35 would be qualified

scientists or technologists. The company's expenditure on its own research would consequently amount to about £250,000 a year*. In addition the company would make financial contributions to the industry's research association and to universities and other research institutions. On the average for the industry such contributions amount at present to about 25 per cent and 15 per cent respectively of the cost of research carried out by companies themselves. The total research expenditure of the representative company can thus be assessed at about £350,000 a year.

16. As applied to any single company, the foregoing method of estimating research requirements is, of course, crude; some companies would in practice require less and others more. However the Board believe that it provides a reasonable guide as to the total research expenditure at which the industry as a whole should now aim. It leads to the conclusion that the industry should aim at a research expenditure amounting to about 1 per cent of turnover.

17. This conclusion may be tested by comparing the research expenditure of the British industry with that of iron and steel industries in other countries. The information the Board have been able to obtain, both from published sources and by private enquiry, is not sufficient for a conclusive comparison. There is, however, evidence that in 1959 the research expenditure of the iron and steel industries in the U.S.A. and in France amounted in each case to about 1 per cent of turnover and that in Japan the proportion to-day is about 0·85 per cent of turnover. The research expenditure of the British industry amounted to about 0·46 per cent of turnover in 1959; it had increased to about 0·63 per cent by 1962 but there can be little doubt that it was still considerably lower than the proportions in the three other countries referred to. The research expenditures of the American and Japanese industries are doubtless inflated by the absence of co-operative research associations; but the French industry has a strong research association with an expenditure of about three times that of the British Iron and Steel Research Association. It is therefore, reasonable to conclude that the British industry should aim at a research expenditure of not less than 1 per cent of turnover if it is to be on a par in this respect with the foreign iron and steel industries that have the highest research ratios.

18. The Board do not, of course, suggest that research expenditure should be tied inflexibly to a proportion of turnover; turnover is subject to fluctuations for reasons that have no relevance to the amount that should be spent on research. The Board consider, however, that 1 per cent of turnover is a reasonable approximate measure of the total research expenditure at which the general branch of the industry should now aim. The Board's 1962 enquiry showed that in 1961–62 this branch was spending about £6 million a year on research related to products with which the Board are concerned and that its turnover in these products was about £950 million a year†. The objective which the Board suggest would call for a research expenditure of between £9 million and £10 million a year. The Board recognise that it will necessarily take time to achieve such a substantial increase; but, in their view, the increase should be brought about as

* The Board's 1962 enquiry showed that the cost of research in the steel industry amounted, on average, to nearly £2,200 a year a head for all grades of research staff.

† See the table (and footnote) in para. 1 of chapter 3 above. The turnover subsequently fell but by the autumn of 1963 it had recovered to at least the same level. Expenditure on research has risen since 1961–62.

quickly as additional resources can be obtained and efficiently deployed. This will largely depend on the speed with which additional scientists and engineers can be recruited.

19. It was suggested to the Board's Technical Advisory Panel that the industry had been in a relatively unfavourable position as regards recruitment from universities. The Panel were glad to note that the British Iron and Steel Federation had taken steps to improve the industry's position in this respect and that there had been an increase in the proportion of scientifically qualified employees in the industry. The Panel considered that scientists and technologists took a more prominent part in management in some other countries than in Britain, and that their general standing was often higher. This appeared to be specially the case in Germany and Japan, where large technical institutes, at Aachen and Kansai respectively, specialise in training iron and steel technologists and provide a source of recruits with training and experience in iron and steel research. The Panel recommended that further steps should be taken to make the industry, and the opportunities it offers, more widely known among students and to expand the rate of scientific recruitment to the industry. The Panel accordingly suggested that the industry should establish a closer liaison with universities and colleges of advanced technology and increase its support of post-graduate research. The Panel also suggested that the industry might consider the endowment of teaching posts as a means of promoting interest in the industry's problems.

20. In considering whether the industry's research is adequate, it is necessary to look at the performances of its constituent companies as well as to the performance of the industry as a whole. For companies in the iron and steel industry there is a wide range of variation in the ratio of research expenditure to turnover. The Board's 1959 enquiry showed that, if companies were arranged in the order of this ratio, the average ratio for the industry as a whole was only one-third of the average of the leading 25 per cent of companies. The leading 25 per cent included many manufacturers of alloy steel whose circumstances tend to require a relatively high expenditure on research. If these were excluded throughout, the average ratio for the leading 25 per cent of companies was about 1 per cent, while the average for the industry as a whole was only about half of this. It should, therefore, be well within the industry's power to raise its rate of expenditure on research to about 1 per cent of turnover.

21. The Board recognise that, just as the research ratios of different industries should not necessarily be the same, the research ratios of companies within the same industry may properly differ. In the iron and steel industry, however, some companies are at present content to rely entirely on the services of the central research association. The Board consider that no major company of national standing should be without a research department with enough scientific staff to carry out both laboratory and field work on the company's current problems and in anticipation of its future needs. Some of the smaller companies may not be able to maintain a research staff on the scale suggested in para. 15 above. Every company should, nevertheless, have some scientific staff free from production responsibilities and thus able to keep in touch with the work done by research associations and other outside bodies and to apply

the results of such work to the company's problems. Ideally, all companies that undertake research should include in their top management at least one qualified scientist or engineer, either as a member of the board of directors or with full access to the hoard, so that the company's research may be interpreted to the hoard and properly related to the company's policy. This is already the practice in the major iron and steel companies.

22. In industrial research, the allocation of resources should take into account the prospects of commercial return. A good research director will allocate the resources at his disposal to the projects that appear to be the most promising from the point of view of the chance of success and the probable commercial value of the results. He will equally be ready to stop projects promptly if they cease to be sufficiently promising. It follows from these considerations (and also from the need for special attention, in research, to developments that will reduce costs of production) that those who are responsible for the direction of research should take commercial as well as technical factors into account and should inform themselves about capital and operating costs of production in the industry. In recent years there has been a marked increase in the collaboration hetween the costing and the technical departments of companies; but there is still room for further improvement in some cases. A similar collaboration is required between the central research associations and their constituent members; it has been growing, and should be encouraged and extended.

The Foundry Branches of the Industry

23. Like the general hranch of the industry, the foundry branches are also suhject to increasingly severe competition and there is a similar need for a suhstantial increase in their expenditures on research.

Ironfounding

24. The ironfounding industry includes a large number of companies that are too small to undertake research on a substantial scale. It is therefore largely dependent for its research on the British Cast Iron Research Association. The Association's main source of income is a contribution paid by the Joint Iron Council from the proceeds of a voluntary levy on producers of foundry pig-iron. The Association represented to the Board's Technical Advisory Panel that the income of the Association was not sufficient to pay for several subjects that needed investigation. The Panel recommended that the Board should discuss with the organisations concerned how the income of the Association could be increased. As a result of discussions between the Joint Iron Council, the British Cast Iron Research Association and the Board, the Joint Iron Council have undertaken to increase the contrihution the Council makes to the Association from the proceeds of the voluntary levy on producers of foundry pig-iron, and the Association is taking steps to increase its income from other industrial sources. These measures are expected to lead to an increase of from 40 to 50 per cent in the average annual income of the Association in its next five-yearly financial period, beginning in 1965.

Steelfounding

25. The steelfounding industry is also largely dependent for research on its research association, namely the British Steel Castings Research Association. The Association informed the Board's Technical Advisory Panel that the income of the Association was not sufficient for some desirable extensions of the

Association's activities. The income of the Association is provided mainly by voluntary contributions from steelfounders on the basis of their wages bills. These contributions are already higher in relation to turnover than members' contributions to research associations in most metallurgical industries; and it is unlikely that an increase in the rates of subscription would be acceptable to the members of the Association. An increase in the income of the Association therefore depends either on an increase in the output of the industry or on enlisting additional members; the present membership of the Association represents about 80 per cent of the industry's output. The Panel recommended that the Board should discuss with the organisations concerned what steps might be taken to encourage support of the Association, particularly by steelfounders who were not members. After discussion with the British Steel Founders' Association, the Board made an enquiry of steelfounders who were not, at the time, members of the Research Association; but this enquiry has not so far resulted in a substantial increase in membership.

Chapter 8

Summary of Main Conclusions

1. The industry has solid and valuahle achievements to its credit in research since the end of the war; and a few companies have heen outstanding in extending the range of their research well heyond their immediate requirements. The industry makes use of all the forms of organisation that have heen estahlished in Britain for industrial research; iu particular, it maintains three research associations, one of which, the British Iron and Steel Research Association, is the largest co-operative industrial research association in this country. The industry is outstanding in its co-operation to avoid wasteful duplication of research. It has also been quick to adopt new research techniques and to enter new fields such as operational research.

2. During the past few years there has heen a radical change in the circumstances of the industry. For many years after the war, it had no difficulty in selling all it could produce and was indeed making every effort to increase its capacity. It is now suhject to growing competition hoth from rival steelworks ahroad, many of which enjoy greater natural advantages, and from rival materials. In a number of fields, the resources applied to research could he increased with prospective commercial benefit. For these reasons a substantial increase is called for in the research effort of all branches of the industry.

3. How much an industry needs to spend if its research is to be adequate is a matter of judgement; there is no decisive quantitative test. A number of considerations lead the Board to the conclusion that a research expenditure amounting to ahout 1 per cent of turnover is the hroad objective which the general branch of the industry should now set itself. This proportion should not, of course, he regarded as a maximum for individual companies; some companies already spend more on research and will no douht continue to do so. In 1961–62 the general hranch of the industry was spending ahout £6 million a year on research related to products with which the Board are concerned and its turnover in these products was about £950 million a year. The objective which the Board suggest would call for a research expenditure of hetween £9 million and £10 million a year.

4. Such a suhstantial increase in expenditure will necessarily take time to achieve; hut it should he hrought ahout as quickly as additional resources can he ohtained and efficiently deployed. This will largely depend on the speed with which the industry can recruit additional scientists and engineers. The industry should accordingly take further steps to strengthen its connection with universities and other centres of higher education, and to improve its recruitment of qualified research staff.

5. The extent to which companies should increase their individual research efforts, and the extent to which additional resources should he provided for

co-operative research through research associations or otherwise, are questions for companies individually, and for the industry collectively, rather than for the Board to decide. Several specific suggestions have been made in this report (para. 11 in chapter 7 above) as to fields that would benefit from an increase in the resources applied to research. Among the general considerations that should guide the allocation of resources, the following appear to the Board to be of special importance:—

(a) Since the industry has recently invested a large amount of capital in modern plant which may be expected to last for many years, a great deal of research will properly be directed to improving existing plant and processes. A considerable increase is, nevertheless, required in the resources devoted to research that looks much further ahead. This work should be directed to radical changes in techniques and should have as one of its objects the ultimate replacement of batch production by continuous processes.

(b) The provision for large-scale work on pilot or production plant should be increased; arrangements should be made more frequently than in the past for such work to be financed co-operatively if it is likely to be of value to several producers.

(c) Improving the competitive position of the industry both now and for the future should be a principal aim in all branches of the industry's research. Whether research is directed to improving existing processes or to developing new and radically different processes, special attention should be paid to developments that promise to reduce costs of production, particularly capital costs for each unit of output. Technical research in aid of market development is of increasing importance.

6. A substantial increase is needed in the research expenditure of the foundry branches of the industry. These branches depend mainly on their respective research associations for their requirements in research. In both cases there is agreement that, for an adequate programme of research, the association requires a larger income. Steps have been taken that should eventually lead to an increase of from 40 to 50 per cent in the annual income of the British Cast Iron Research Association. The Board have under further consideration the question how the income of the British Steel Castings Research Association might be increased.

7. No company should be content to rely exclusively on the services of research associations. Major companies of national standing should maintain research departments with sufficient staff to deal with the special problems already facing the company and to undertake work in anticipation of its future needs. Smaller companies should, as a minimum, have some scientific staff free from production responsibilities and thus able to keep in touch with research done elsewhere and to apply the results to the company's needs. All companies that undertake research should include in their top management at least one qualified scientist, or engineer, either as a member of the board of directors or with full access to the board, so that the company's research may be properly related to the company's policy.

8. Those responsible for the direction of research should be encouraged to take commercial as well as technical factors into account and should be given facilities to inform themselves about production costs.

Appendix I

MEMBERSHIP OF THE BOARD'S TECHNICAL ADVISORY PANEL

1. The initial members of the Technical Advisory Panel were:—

Sir Robert Shone, C.B.E. .. .. (*Chairman*)	Executive Member, Iron and Steel Board.
Sir Alan Wilson, F.R.S... .. .. (*Deputy Chairman*)	Member, Iron and Steel Board. Deputy Cbairman and Managing Director in cbarge of Research and Development, Courtaulds Ltd. (Now Chairman, Glaxo Group Ltd.).
Professor J. F. (now Sir John) Baker, O.B.E., F.R.S.	Professor of Engineering, University of Cambridge.
Mr. W. F. Cartwright	Assistant Managing Director (now Managing Director), The Steel Company of Wales Ltd.
Professor A. H. Cottrell, F.R.S. ..	Professor of Metallurgy, University of Cambridge.
Sir Charles Goodeve, O.B.E., F.R.S. ..	Director, British Iron and Steel Research Association.
Sir Arnold Hall, F.R.S...	Managing Director, Bristol Siddeley Engines Ltd. Director, Hawker Siddeley Group Ltd.
Dr. A. H. Leckie..	Head of Technical and Researcb Division, Iron and Steel Board.
Mr. H. Morrogh..	Director, British Cast Iron Research Association.
Mr. (now Dr.) F. H. Saniter, O.B.E. ..	Director of Research, The United Steel Companies Ltd.

2. Sir Robert Shone retired from the Panel in Marcb, 1962, having ceased to be the Executive Member of the Board. He was succeeded as Chairman of the Panel by Sir Alan Wilson, and Mr. R. W. Foad, the new Executive Member of the Board, joined the Panel as Deputy Chairman.

3. Dr. A. H. Sully, Director, Britisb Steel Castings Research Association, became a member of the Panel in May, 1962.

Appendix II

RESEARCH RATIOS IN BRITISH MANUFACTURING INDUSTRY

(See para. 9 in chapter 7)

1. The research ratios estimated in the D.S.I.R. 1959 enquiry* are summarised in the following table:—

Industry or group of industries	Research expenditure as a percentage of net output
All manufacturing industries	3·8
All manufacturing industries except aircraft	2·6
Ceramics, glass, cement, etc.	1·1
Chemicals and allied trades	5·9
Metal manufacture	1·15
of which: iron and steel (a)	0·9(b)
non-ferrous metals	2·1
Non-electrical engineering and shipbuilding	1·8
Electrical engineering and electrical goods	9·8
of which: electronics	11·9
Aircraft	35·7
Motor and other vehicles and accessories	3·3
Precision instruments, etc.	10·7
Textiles, leather, leather goods and clothing	0·9
Food, drink and tobacco	0·6
Manufactures of wood and paper, and printing	0·25
Other manufacturing	1·8

(a) Including ironfoundries.

(b) The research ratios given in the body of the report for the British and some foreign iron and steel industries relate to gross output and are, therefore, not comparable with the ratios shown above.

2. The following estimated research ratios are taken from the report of the F.B.I. enquiry*. All the figures refer only to research carried out by manufacturers in their own organisations; they do not cover, for example, research carried out by research associations or by universities with financial aid from manufacturers.

	No. of Q.S.E. (a) for each 100 employees	No. of Q.S.E. (a) for each £100,000 of fixed assets	Research expenditure for each 100 employees
			£
Average for all industries	0·66	0·36	5,801
Average for all industries except aircraft	0·59	0·32	3,910
Iron and steel (b)	0·20	0·06	909

(a) Qualified Scientists and Engineers.

(b) Including ironfoundries.

* For references see notes (b) and (c) to the table in para. 12 of chapter 1.

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